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Evaluation of Triple Independent Instrument Landing System Approaches to Runways Spaced 4,000 Ft and 5,300 Ft Apart Using A Precision Runway Monitor System

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16. Abstract

The Multiple Parallel Approach Program (MPAP) performed a real-time simulation to evaluate simultaneous Instrument Landing System approaches to three parallel runways spaced 4,000 ft and 5,300 ft apart. Air traffic controllers monitored traffic using a simulated Precision Runway Monitor (PRM) system, which consisted of Final Monitor Aid displays and a simulated radar update rate of 1.0 second. The MPAP test team introduced aircraft blunders to test the air traffic control system ability to maintain adequate separation between aircraft on final approaches during critical situations using the proposed runway configuration. The MPAP Technical Work Group (TWG) developed four criteria to evaluate the study: 1) the number of Test Criterion Violations relative to the total number of at-risk, non-responding blunders, and relative to a predetermined target level of safety of no more than one fatal accident per 25,000,000 approaches; 2) the frequency of No Transgression Zone entries and nuisance breakouts; 3) an evaluation of controller communications workload; and 4) an operational assessment from MPAP TWG members and participating controller and pilot technical observers. The results of the simulation passed all of the test criteria. The MPAP TWG therefore recommended the 4,000 and 5,300-ft triple approach procedure for approval in the operational environment, given similar controller and pilot training, when the PRM system is used.

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Executive Summary

This simulation tested the procedure for independent Instrument Landing System (ILS) approaches to three parallel runways spaced 4,000 ft and 5,300 ft apart. Controllers monitored aircraft arrivals using a Precision Runway Monitor (PRM) system, which consisted of Final Monitor Aid displays and a simulated Electronic Scan radar sensor with a 1.0-second update rate.

The Multiple Parallel Approach Program (MPAP) test team initiated aircraft blunders to evaluate the ability of the system to maintain distances of at least 500 ft between aircraft during critical blunder situations. A blunder occurred when a Target Generation Facility computer-generated aircraft, established on an ILS approach, made an unexpected 30-degree turn toward an aircraft, usually a flight simulator, on an adjacent approach. Pilots of 80% of the blundering aircraft were instructed to disregard controller communications, simulating an inability to comply with controller instructions. The test team conducted statistical analyses on the non-responding aircraft blunders involving flight simulator targets. Test criterion violations (TCVs) resulted when the separation between aircraft was less than 500 ft. For blunders that would have resulted in aircraft miss distances of less than 500 ft, had there been no controller intervention, the test team classified them as at-risk.

The MPAP Technical Work Group (TWG) developed the following criteria to evaluate the study:

a. the number of TCVs relative to the total number of at-risk, non-responding blunders and to a predetermined target level of safety of no more than one fatal accident per 25,000,000 approaches;
    - The test team used both the real-time simulation data and Monte Carlo technique for this assessment.

b. the frequency of No Transgression Zone (NTZ) entries and nuisance breakouts (NBOs);
    - NTZ entries occurred when aircraft entered the NTZ, not including aircraft that were directed to blunder. NBOs resulted when aircraft were broken out of the final approach for reasons other than a blunder, NTZ entry, loss of longitudinal separation, or lost beacon signal.

c. an evaluation of controller communications workload; and

d. an operational assessment from MPAP TWG members, based on their expertise and judgment, and on evaluations from participating controller technical observers.

During the simulation, the MPAP test team initiated 146 at-risk blunders. Of the 146 blunders, 125 were non-responding, classifying them as worst-case blunders (WCBs). Three TCVs occurred in the WCB situations. The TCV rate resulting from the real-time simulation was 2.4%. The confidence interval for the true TCV rate, based on the real-time results, was 0.272 to 8.506%. The TCV rate resulting from the Monte Carlo simulation with 30% heavy jets was 0.899%. The confidence interval for the true TCV rate, based on the Monte Carlo simulation results, was 0.824 to 0.979%. This result was consistent with the real-time simulation results and below the test criterion of 5.1%. In addition, the test procedure achieved a target level of safety of no more than one fatal accident per 25 million approaches.

The MPAP TWG conducted an evaluation of NTZ entries and NBOs to assess system capacity and controller workload. In the approach course configuration, no NTZ entries occurred as a result of Total Navigation System Error (TNSE). The TWG defined TNSE for this simulation as the difference between the actual flight path of the aircraft and its intended flight path. Only 5 NBOs occurred in 2,586 non-blunder-related approaches (0.2%) due to TNSE-related events (i.e., aircraft approaching the NTZ). Both results were considered acceptable.

The TWG determined that the controller communications workload associated with TNSE-related events was at a satisfactory level based on their observations during the simulation and on questionnaires from participating controllers.

The MPAP TWG unanimously agreed that this 4,000- and 5,300-ft configuration met all of the test criteria. Participating controller observers and pilot site coordinators also supported this position. Modifications to the controller training and breakout phraseology since a previous 4,000- and 5,300-ft simulation along with the introduction of pilot training in that previous simulation were significant in enabling a successful operation.

The MPAP test team trained controllers extensively for this simulation. Controllers were each given 8 hours of hands-on training to familiarize themselves with PRM procedures and equipment. Controllers were able to observe and take action to resolve blunders while using new breakout phraseology (modified from a previous simulation to be more concise and effective at conveying the urgency of the situation). In addition to the hands-on training, the test team educated controllers on cockpit procedures when breakout instructions are issued. They showed video recordings of crews initiating breakouts in flight simulator aircraft. The purpose of the video presentation was to allow controllers to make educated decisions.

The pilot training began with all participating line pilots viewing a video describing the PRM system (FAA, 1995). After viewing the video, the pilots read a Pilot Awareness Training Bulletin and took a self-administered test on pilot awareness. Pilots who flew glass cockpit simulators, an MD90 and a B747-400, were also required to read a Breakout Procedure Bulletin and complete a self-administered test on what they had learned. Pilots who had been trained in a previous simulation (within 12 months of the current simulation) received no additional training. Pilots assigned to the General Aviation Trainer had all viewed the video and received Pilot Awareness Training within the previous 12 months with the exception of one pilot. This pilot had not participated before and was trained only by viewing the video. All pilots were required to hand-fly breakouts.

The test results demonstrated that the modified controller training and phraseology and the pilot training improved the procedure over previous simulations that had less controller training and no pilot training. Controller and pilot responsibilities were clearly understood, response times were sufficient, and the target level of safety of no more than one fatal accident in 25 million approaches was achieved. The TWG, therefore, recommended the procedure on simultaneous approaches to three runways spaced 4,000 ft and 5,300 ft apart for approval in the operational environment, given similar controller and pilot training, when the PRM system with a 1.0-second update rate is used.

1. Introduction

The ability of the National Airspace System (NAS) to meet future air traffic demands is a serious concern. Programs to improve NAS capacity have been underway since the early 1980s, both to reduce air traffic delays and to accommodate the increased demand. Contributing to capacity problems are the limitations imposed by current airport runway configurations and the associated air traffic separation criteria, particularly as related to aircraft executing Instrument Landing System (ILS) approaches under instrument meteorological conditions (IMC).

One way to improve system capacity and efficiency is to permit the conduct of simultaneous approaches to airports with parallel runways. In 1988, the Federal Aviation Administration (FAA) established the Multiple Parallel Approach Program (MPAP) to investigate simultaneous ILS approach operations to various dual, triple, and quadruple parallel runway configurations as a means of enhancing capacity. Through the performance of real-time simulations, the MPAP demonstrated that simultaneous approaches can increase the NAS capacity and reduce operational delays. Furthermore, simultaneous approach procedures can be incorporated into many airport operations with a minimal level of expenditure. In many cases, airports can modify or use their existing runway layouts to allow simultaneous operations, eliminating the need to build new runways or new airports.

The MPAP Technical Work Group (TWG) has sponsored a number of simultaneous approach operations to dual, triple, and quadruple parallel runway configurations through real-time simulation (Appendix A). The MPAP TWG consists of FAA representatives from the Secondary Surveillance Product Team, Office of System Capacity, Flight Standards Service, Air Traffic Rules and Procedures Service, Air Traffic Plans and Requirements, and the Southwest Region.

The MPAP TWG brings together various areas of expertise to evaluate the feasibility of multiple parallel approaches in an effort to increase airport capacity in a safe and acceptable manner. The main objective of the TWG is to determine the minimum acceptable spacing between parallel runways for different simultaneous approach configurations while maintaining a specified, conservative target level of safety. The TWG and various research organizations included on the MPAP team, evaluate simulated proposed operations against specific test criteria that have been developed over the course of many real-time simulations. Only after extensive review and evaluation of simulation results does the TWG conclude whether or not a proposed procedure should be recommended for approval in the operational environment.

1.1 Background

The MPAP team conducted a real-time simulation in April 1996 to evaluate simultaneous approach operations to three parallel runways spaced 4,000 ft and 5,300 ft apart. The team tested this runway configuration to emulate proposed operations at Hartsfield Atlanta International and Pittsburgh International Airports. Currently, triple simultaneous ILS approaches are authorized, using conventional display and radar system technology, to runways spaced 5,000 ft apart and greater at airports with field elevations of less than 1,000 ft msl. Using advanced controller display technology, however, triple simultaneous approaches are authorized to runways spaced 4,300 ft apart and greater at airports with field elevations of less than 1,000 ft msl (FAA, 1996a).

The April 1996 triple approach simulation tested the 4,000- and 5,300-ft procedure using a Precision Runway Monitor (PRM) system. The PRM consists of a high-resolution display system, such as the Final Monitor Aid (FMA) display, and a monopulse antenna system that provides high azimuth and range accuracy and higher update rates than the current Airport Surveillance Radars. The PRM system was developed in the late 1980s specifically for the monitoring of closely spaced parallel approaches. PRM systems allow simultaneous ILS approaches to be conducted where they were previously restricted due to existing runway spacing and radar error.

1.2 Simulation-Related Definitions

The MPAP test team developed definitions and classifications that are specific to the MPAP real-time simulations. The following sections explain the simulation-related terms to which we refer throughout the report.

1.2.1 Blunders

During MPAP simulations, the test team initiates aircraft blunders to measure the ability of the system to maintain adequate separation between aircraft on final approaches during critical situations. A blunder occurs when an aircraft, already established on the final approach course, makes an unexpected turn towards another aircraft on an adjacent approach (see Figure 1). Adequate separation is maintained and the blunder is considered resolved if the minimum slant distance between the blundering and the evading aircraft at the closest proximity is 500 ft or greater.

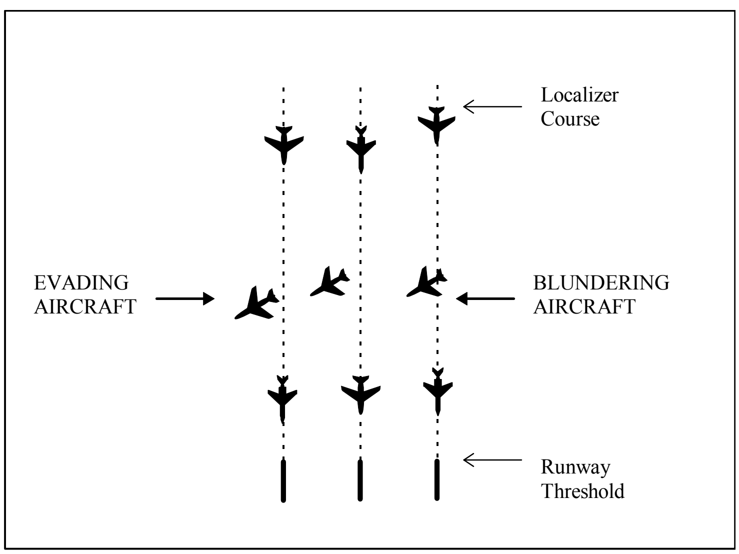


Figure 1. Aircraft blunder during parallel approach operations.

1.2.1.1 Test Criterion Violations

The TWG considers any blunder that results in a miss distance of less than 500 ft between aircraft to be a Test Criterion Violation (TCV). A valid TCV is one that could occur in the operational environment for any number of reasons and is not the result of a simulation anomaly (e.g., simulation hardware and software failure). If a blunder results in a TCV, the TWG considers it unresolved.

1.2.1.2 Blunder Classifications

One way to classify blunders is by the severity of the situation. For instance, the TWG classifies blunders as at-risk or not at-risk. An at-risk blunder is one that would have resulted in a miss distance of less than 500 ft had evasive maneuvers not been executed by either the blundering or the evading aircraft. An at-risk blunder is determined mathematically, based upon the projected courses of the blundering and evading aircraft at the start of the blunder. A blunder that is not at-risk is one that would have resulted in a miss distance of 500 ft or greater without any evasive action being taken.

The TWG also classifies blundering aircraft as responding or non-responding. A responding aircraft is one in which the pilot of the blundering aircraft verbally responds to the controller's instructions and attempts to return the aircraft to the localizer course or execute some other evasive maneuver. A non-responding aircraft is one in which the test director instructs the pilot to disregard controller communications, simulating an inability to correct the deviation from the approach course. This inability to correct a blunder is intended to simulate situations involving communication problems, hardware failures, and/or human error.

Blundering aircraft are scripted to turn at predetermined angles towards adjacent approach courses. In this simulation, all blundering aircraft executed 30-degree turns. A worst-case blunder (WCB) occurs when the blundering aircraft turns at an angle of 30 degrees and is non-responding. In addition, blundering aircraft may either maintain altitude or descend.

1.2.2 No Transgression Zone Entries and Nuisance Breakouts

The final approach airspace is divided into two areas between the runways, the Normal Operating Zone (NOZ) and the No Transgression Zone (NTZ), as shown in Figure 2. The NOZ is the area between the NTZ and the final approach course where aircraft are permitted to fly. The NTZ is the 2,000-ft wide area equidistant between final approach courses where aircraft are not permitted to enter.

If an aircraft enters the NTZ, FAA regulations require the monitor controller to break that aircraft and any adjacent aircraft out of the approach. Because the NTZ is fixed at 2,000 ft, the NOZ varies with runway separation. As separation between runways decreases, the NOZ decreases, providing less airspace for aircraft to fly along the ILS and a greater opportunity for aircraft to enter the NTZ.

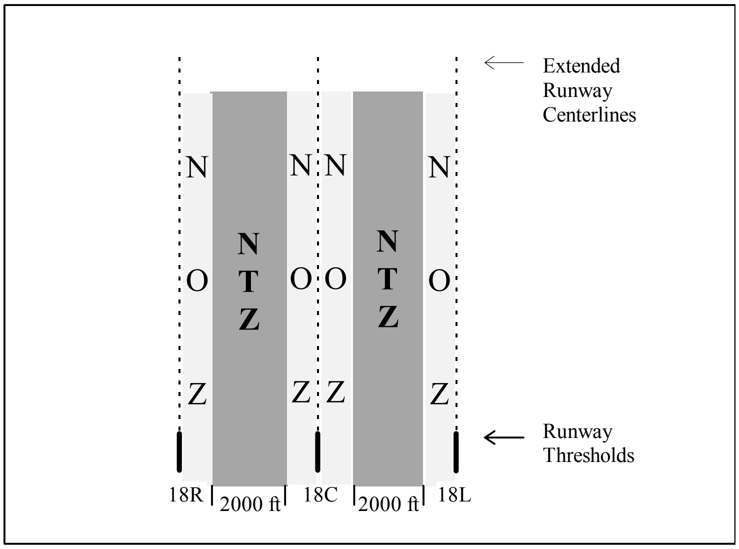


Figure 2. Normal operating zone and no transgression zone.

As runways become more closely spaced, Total Navigation System Error (TNSE) becomes a concern. TNSE represents the difference between the actual flight path of an aircraft and its intended flight path. Flight technical error (FTE), avionics error, ILS signal error, and/or weather can cause TNSE. TNSE may contribute to the occurrence of NTZ entries and nuisance breakouts (NBOs). An NTZ entry occurs when an aircraft enters the NTZ for reasons other than a blunder or breakout. An NBO occurs when an aircraft is broken out of its final approach course for reasons other than a blunder, loss of longitudinal separation, or lost beacon signal (i.e., aircraft target goes into coast).

2. Methodology

2.1 Acceptance Criteria

The MPAP TWG uses four criteria to evaluate simulated operations: the TCV rate and risk analysis, the frequency of NTZ entries and NBOs, the controller communications workload, and a TWG operational assessment.

2.1.1 Test Criterion Violation Rate and Risk Analysis

2.1.2 Test Criterion Violation Rate Derivation

The TCV rate is a measure of the system blunder resolution capability. The MPAP test team evaluates individual blunders to determine whether or not they are at-risk. The number of TCVs divided by the number of at-risk blunders results in an initial estimate of the TCV rate. The number of at-risk, non-responding blunders that occurs during the real-time simulation, however, is relatively low, and therefore a large confidence interval results.

To ensure a more accurate measurement of the operational TCV rate, this criterion is measured using a fast-time computer, or Monte Carlo, simulation. The Monte Carlo simulation, named the Airspace Simulation and Analysis for Terminal Instrument Procedures (ASAT) Model, uses data collected in the real-time simulation to model over 100 thousand at-risk blunders, thus reducing the range of the confidence interval to a very small size. Appendix B describes the method used in the Monte Carlo simulation.

The MPAP test team compares the TCV rate estimate from the Monte Carlo simulation to the results of the real-time simulation to ensure consistency. Appendix C contains specific procedures for the evaluation of TCV rate and risk analysis.

2.1.2.1 Maximum Acceptable Test Criterion Violation Rate

The MPAP test team adopted a method for determining a simulation's maximum acceptable TCV rate from the PRM Demonstration Program. In the PRM Demonstration Report (PRM Program Office, 1991), researchers computed a TCV rate from the population of all WCBs. They found that a TCV rate not greater than 0.004 TCV per WCB would meet the target level of safety, provided that the overall 30-degree blunder rate did not exceed one 30-degree blunder per 2,000 approaches.

The real-time simulation, however, measures a TCV rate based on at-risk WCBs, not the population of all WCBs. Therefore, for comparison purposes, the population TCV rate is converted to an at-risk TCV rate. Based on a simulation of aircraft speeds and types, a conservative ratio of 1/17 at-risk WCB per WCB is applied, resulting in an at-risk TCV rate criterion of 5.1 percent for triple approaches (see Appendix C). The MPAP test team also determined that the criterion for dual approaches is 6.8%. For the triple approach operation, the MPAP TWG determined that 1) the triple approach must meet the criterion for triple approaches, and 2) each proximate pair must meet the criterion for dual approaches. This is so because it is possible that the criterion for the triple approach could be met, however, one of the proximate pairs of runways did not meet the criterion for dual approaches.

2.1.2.2 Relationship between Test Criterion Violation Rate and Risk Analysis

For this simulation, a Monte Carlo at-risk TCV rate confidence interval not exceeding 5.1% for the triple approach and an at-risk confidence interval not exceeding 6.8% for each proximate pair of dual approaches would indicate a fatal accident rate below the target level of safety and would thus be acceptable. A Monte Carlo confidence interval that extends above 5.1% for the triple approach or 6.8% for the dual approach would indicate that the operation might not meet the target level of safety.

2.1.3 Frequency of No Transgression Zone Entries and Nuisance Breakouts

Measuring the frequency of NTZ entries and NBOs provides an assessment of how TNSE affected the simulated approach configuration. All NTZ entries and NBOs that occur as a result of TNSE are examined. The frequency of NTZ entries and NBOs has to be at an acceptable level as determined by the MPAP TWG.

2.1.4 Controller Communications Workload

The MPAP test team developed the controller communications workload criterion as a result of past simulation observations of the effects of TNSE-related events. As runways become more closely spaced, the opportunity for NTZ entries and NBOs increases, as does radio frequency congestion due to those TNSE-related events. The TWG, therefore, considers controller communications workload in their assessments of each simulation. They make a subjective evaluation of the acceptability of the communications workload required of the controllers to maintain aircraft flight courses within the NOZ.

2.1.5 Technical Work Group Operational Assessment

MPAP TWG members conduct an operational assessment of the tested approach configuration. The assessment reflects the TWG's overall evaluation of the simulated procedure and recommendation regarding the feasibility of implementing the procedure in the operational environment. The operational assessment is based on all test results, on MPAP TWG expertise and judgment, and on evaluations from subject controllers and participating controller technical observers.

2.2 Simulation Overview

2.2.1 Previous 4,000- and 5,300-ft Triple Approach Simulation

The MPAP test team first simulated the 4,000- and 5,300-ft triple approach procedure using the PRM in August 1995. The procedure was not recommended for approval, however, as tested. Although some of the test acceptance criteria were met, the blunder resolution performance results were not acceptable. Controller training was identified as a major contributing factor to the unacceptable TCV rate results. The amount of controller hands-on training with the PRM equipment and controller breakout phraseology (i.e., format and delivery), specifically, was inadequate to support the procedure.

A large number of controllers rotated through as subjects over the course of the simulation. As a result, hands-on training with the PRM equipment prior to testing was limited. Controllers were not accustomed to detecting and resolving blunders. The practice they were given was not enough to familiarize them with such events. In addition, the controllers were not accustomed to certain features of the FMA displays, particularly the horizontal- and vertical-expansion ratios. For example, 30-degree turns were interpreted as 90-degree turns. The August 1995 simulation clearly demonstrated that controller participants needed more practice time on position.

Also, controllers were briefed prior to the simulation on the standard phraseology to be used in the event of a blunder. During the simulation, however, breakout phraseologies varied in content and duration. The prescribed phraseology was lengthy, and as a result, controllers had difficulty remembering words and the prescribed order of the words. Coupled with the limited hands-on training, delivery of the phraseology was poor in many cases. This contributed significantly to the blunder resolution performance. The TWG proposed improving the controller breakout phraseology.

In the August 1995 triple simulation, the MPAP test team introduced pilot training for the first time. The pilot training was very effective at improving the pilots' awareness of the simultaneous close parallel approach environment. The requirement of hand-flying the breakouts shortened the time-to-turn times, especially those of aircraft with highly automated cockpits. Unlike previous simulations, very few of the TCVs in the August 1995 simulation were attributed to pilot performance. Because of the effectiveness of the pilot training introduced in this simulation, it remained the same for the October 1995 dual 3,000-ft offset simulation, which had no TCVs, and the April 1996 triple simulation reported here.

2.2.2 Controller Training Modifications

The MPAP test team took action to resolve the problem areas identified in the August 1995 simulation. TWG members and controller technical observers explored ways to improve controller performance through additional smaller scale studies. They believed that certain training modifications could affect a successful 4,000- and 5,300-ft triple operation.

2.2.2.1 Breakout Phraseology

Several modifications were made to the controller-training program in an effort to increase controller awareness and preparedness for monitoring closely spaced approach configurations. One significant change involved the controller breakout instruction phraseology. In the August 1995 simulation, the prescribed phraseology was the following:

> Aircraft call sign, "Traffic Alert," aircraft call sign, heading, and altitude instructions.

Note: This phraseology was actually modified from a previous simulation that did not include "Traffic Alert" or the second aircraft call sign. The addition of the aircraft call sign in the beginning of the message for the August 1995 triple approach simulation was an attempt to reduce the number of blocked/clipped communications. Even if crews missed the first call sign, they could still hear "Traffic Alert", which was intended to increase awareness of the urgency of the situation, and the second issuance of the call sign. After the August 1995 simulation, the TWG determined that the modified phraseology resolved the clipped communications problems (with the repeat of the aircraft call sign), but the phraseology message itself was too lengthy and delivery was poor in many situations.

As a result, the phraseology was again modified for the April 1996 triple approach simulation. This time, the first aircraft call sign was omitted to allow for an easier, quicker delivery of instructions. "Traffic Alert" at the beginning of the message still served to heighten the awareness of all listeners on the frequency as to the urgency of the impending situation. Furthermore, that phrase alone helped to prevent the clip of the aircraft call sign prior to the breakout instruction. For the April 1996 simulation, the prescribed phraseology was the following:

> "Traffic Alert," aircraft call sign, heading and altitude instructions.

2.2.2.2 Awareness Training

In addition to the new breakout phraseology, controller training for the April 1996 simulation also emphasized the need for a timely response from the controller and highlighted the effect of the controller breakout instruction on the aircrew's workload. The MPAP test team developed a training video using video clips from previous simulations, which demonstrated reactions and responses of flight crews to breakout instructions, including instructions to descend. The training stressed the importance of completing the prescribed phraseology in one transmission. This was based on past observations that information in a later transmission was sometimes missed due to breakout activity in the cockpit or to blocked or clipped communications as the result of frequency usage.

2.2.2.3 Hands-On Training

The MPAP test team increased the amount of controller hands-on training with the PRM equipment for the April 1996 triple simulation to require controllers to complete 8 hours on position prior to participating in actual test runs. Controllers had an opportunity to familiarize themselves with the expanded horizontal axes of the FMA displays. In addition, the training period allowed for sufficient practice of blunder detection and the use of the prescribed breakout phraseology. The TWG determined prior to the simulation that if the 8 hours of hands-on training were effective for the simulation, 8 hours would also be a requirement in the field if the procedure were recommended for approval.

2.2.3 April 1996 4,000- and 5,300-ft Triple Approach Simulation

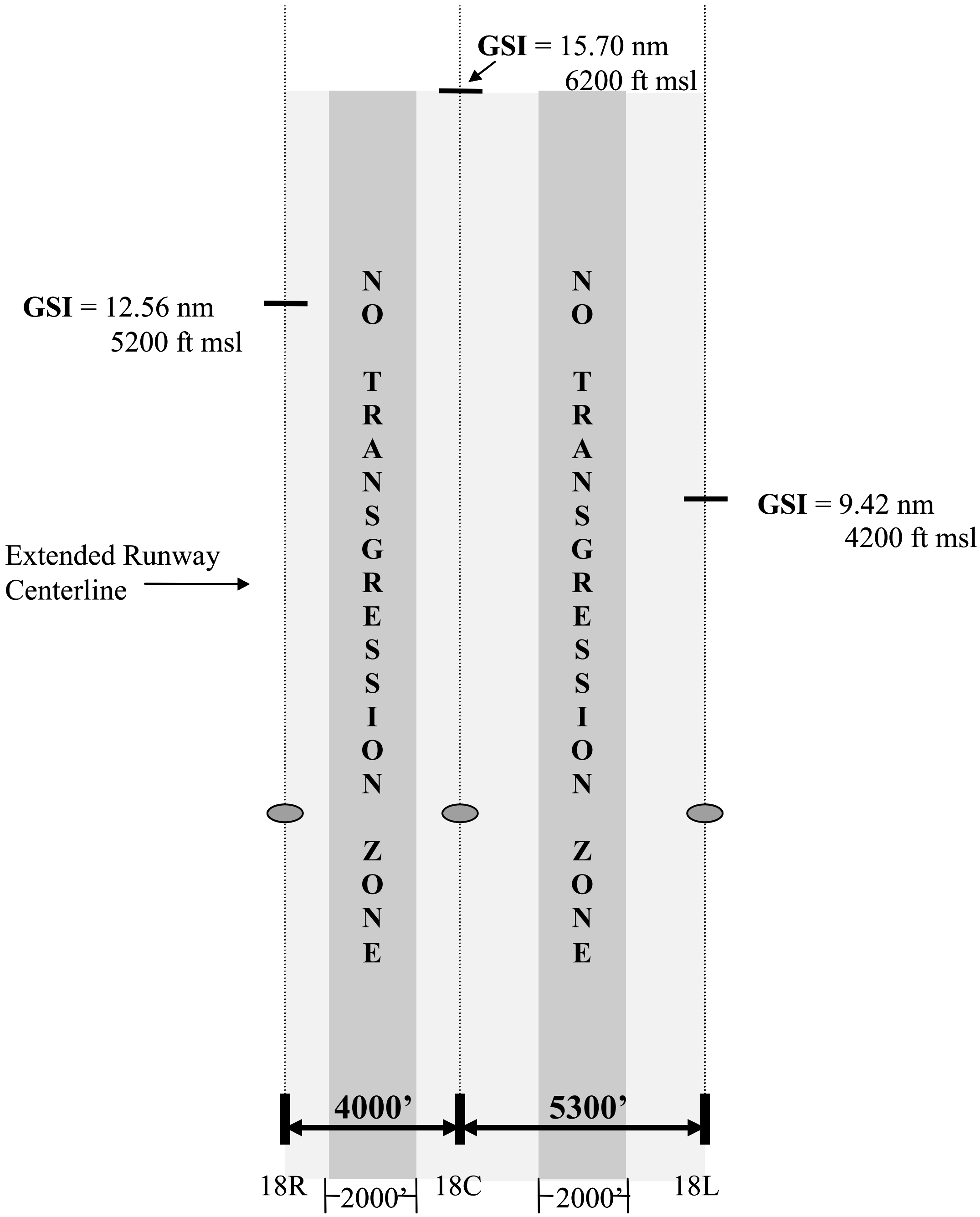
The MPAP test team re-evaluated the 4,000- and 5,300-ft triple simultaneous approach simulation using the PRM system April 14-25, 1996. That study is the focus of the remainder of this report. The controller training modifications were incorporated into the April 1996 simulation. The pilot training that was introduced in the previous August 1995 triple simulation was judged sufficient for this simulation. For details on the evolution of the pilot training components, see Ozmore and Morrow (1996).

2.2.3.1 Airport Configuration

Controllers monitored traffic using a simulated PRM system with a 1.0-second update rate. The airport layout, runways, and arrival frequencies emulated an airport with even thresholds, glide slope of 3 degrees, and field elevation of 1,200 ft (see Figure 3). The turn-on altitude for runway 18R was 5,200 ft msl with a glide slope intercept of 12.56 nm. The turn-on altitude for runway 18C was 6,200 ft msl with a glide slope intercept of 15.70 nm. The turn-on altitude for runway 18L was 4,200 ft msl with a glide slope intercept of 9.42 nm.

2.2.3.2 Test Runs

The MPAP test team performed the simulation over a 2-week period, excluding Saturdays and Sundays. They conducted three 2-hour runs each day. The first week, April 15-19, 1996, was dedicated to controller training. The second week, April 22-26, 1996, was the test week. The team collected and analyzed a total of 15 runs of data.



Airport Elevation:	1200 ft msl
Runways:	10,000 ft x 150 ft
Weather:	200 ft ceiling and 1/2 mile visibility
Mag Variation:	0
Altimeter:	29.92

Figure 3. Airport configuration for 4,000- and 5,300-ft triples.

2.3 Experimental Apparatus

The development of the real-time simulation environment at the William J. Hughes Technical Center in Atlantic City International Airport, NJ, has made real-time simulation testing one of the most advanced methods for evaluating Air Traffic Control (ATC) procedures. The Technical Center laboratories contain fully operational ATC displays that have the capability to interface with remote flight simulators across the country. With this end-to-end simulation capability, researchers can collect and analyze data on controller and pilot performance issues that cannot be measured in the operational environment.

2.3.1 Target Generation Facility Laboratory

The Target Generation Facility (TGF) is an advanced simulation system designed to support testing of current and future ATC systems at the William J. Hughes Technical Center. The functionality of the TGF system is partitioned into three subsystems: simulation pilot, target generation, and development and support.

The simulation pilot workstations (SPWs) are computer workstations containing an AMECOM communications system that for this simulation provided an audio interface with the monitor controllers. Simulation pilot operators (SPOs) used the SPWs to fly simulated aircraft and commanded them in accordance with ATC instructions.

The Target Generation subsystem consists of a Target Generation chassis and an external interface (EI) chassis. The Target Generation performs all modeling within the TGF and correlated dynamic data, such as aircraft state vectors and radar performance, with known flight plans. The EI is responsible for creating the exact form and content of the digitized radar messages sent to the ATC system under test.

The development and support subsystem provides the basic post-exercise data reduction and analysis capabilities. In addition, this subsystem provides the capabilities necessary to maintain and/or enhance the TGF software.

In total, the TGF models a logical view of the ATC environment, including long and short range radar sensors, controlled airspace, weather conditions, air traffic, and aircraft performance. The TGF configuration for the April 1996 simulation is shown in Figure 4.

2.3.2 Radar System and Controller Displays

For this simulation, the final monitor controllers used prototypes of the components of the PRM system located in the Systems Display Laboratory at the William J. Hughes Technical Center. The components consisted of FMA displays and a simulated electronic scanning (E-Scan) beacon sensor with a 1.0-second update rate.

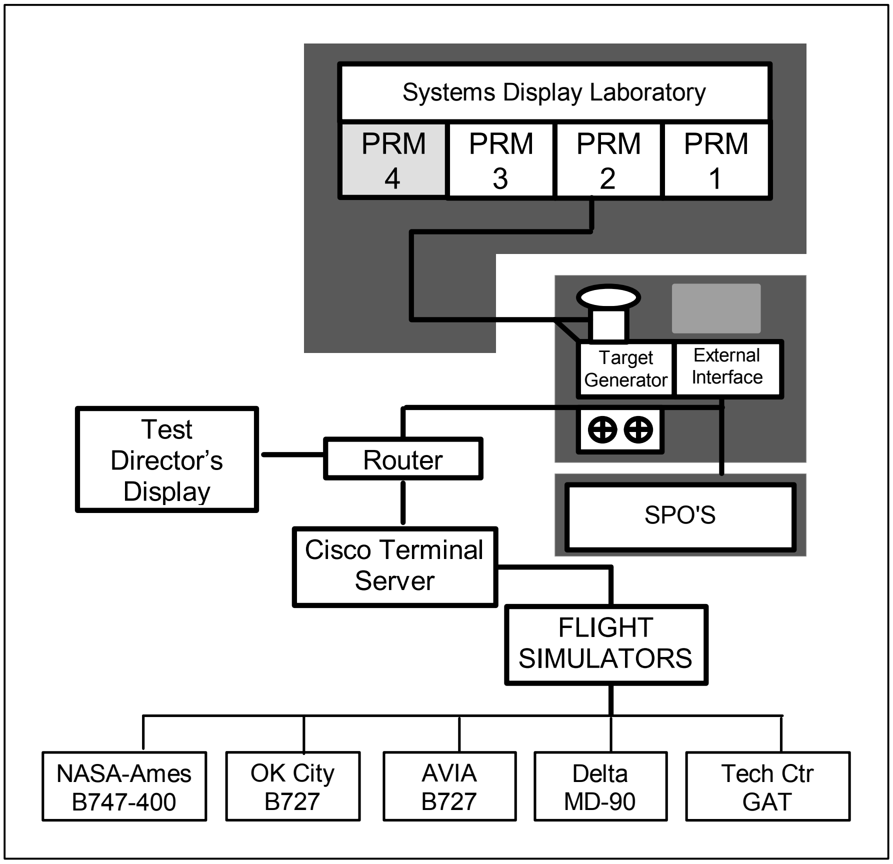


Figure 4. Target generation facility configuration.

A Metheus graphics driver generated the graphics for the FMAs during the simulation and a micro-VAX computer drove the operating system. In addition to the mapping information currently provided by Automated Radar Terminal System displays, the FMAs provided features to aid controllers in the early detection of blunders and the control of airspace. These included independent magnification capabilities, color-coding, aircraft predictor lines, and audio and visual warnings.

FMAs provide the capability to adjust the horizontal and/or vertical ratio of the display. Horizontal and vertical axes can be scaled independently to improve the controller's ability to detect aircraft movement away from the extended runway centerline. For this simulation, the magnification of the controllers' displays was set at 8 times for the horizontal axis and 2 times for the vertical axis, for a 4:1 aspect ratio. Controllers were not permitted to adjust the ratio during the simulation.

For each of the runways, ILS approach centerlines were displayed as dashed white lines, where each dash and each space between dashes represented 1 nm. Solid light blue lines were displayed on each side of the ILS centerlines to delineate 200-ft deviations from the localizers. The 2,000-ft wide NTZ, located equidistant between each localizer course, was outlined in red.

A predictor line was used in the generation of the audio and visual alerts. The predictor line, which was affixed to each aircraft target, indicated where the aircraft would have been in 10 seconds had it continued on the same path. It provided controllers advance notice of the path of the aircraft. It can be varied, but for this simulation the predictor line was set to 10 seconds.

Aircraft targets and alphanumeric data blocks were presented in green as long as aircraft maintained, and were predicted to maintain, approaches within the NOZ. When a predictor line indicated that an aircraft was within 10 seconds of entering the NTZ, the green aircraft target and data block changed to yellow. An auditory warning also sounded at that time (e.g., American 211) to notify controllers of the impending NTZ entry. If an aircraft entered the NTZ, the yellow aircraft target and data block immediately changed to red.

2.3.2.1 Electronic Scanning Radar Sensor

The simulated E-Scan sensor used a monopulse azimuth measurement technique, which provided accuracy of better than 1 milliradian (0.06 degrees) root mean square (rms). The range error associated with the system was ±30 ft with an rms error of 25 ft. The specified system delay from the antenna to the display was up to 0.5 seconds. The alpha-beta tracker, used to smooth aircraft position data, had gains of 0.3 (alpha) and 0.245 (beta) in the calculation of aircraft positions and velocities, respectively.

2.3.2.2 Navigational Error Model

Aircraft position with respect to the final approach course, the NTZ, and other aircraft, had to be realistically presented on the radar display to accurately assess the controllers' ability to detect blunders. In developing the navigational error model for TGF aircraft, two criteria were used. First, aggregate errors had to accurately reflect the TNSE distribution of aircraft as they flew ILS approaches. Second, displayed flight paths of aircraft had to look reasonable to the controllers (i.e., deviations from the localizer centerline had to appear typical of aircraft flying an ILS approach during IMC). The navigational error model used for this simulation was based upon data collected at Chicago O'Hare International Airport (Timoteo & Thomas, 1989), Memphis International Airport (PRM Program Office, 1991), and Los Angeles International Airport (DiMeo, Melville, Churchwell, & Hubert, 1993).

2.3.3 Flight Simulators

The MPAP test team incorporated four full-motion air carrier simulators and one general aviation trainer (GAT) into the simulation. The simulators assumed the configuration of aircraft flying the localizer course and replaced certain TGF aircraft that entered the simulation. Table 1 lists the participating simulator aircraft. Flight simulators were an integral part of the real-time simulation because they provided a representative sample of NAS users. The simulators also generated more accurate pilot and aircraft performance data than the computer-generated aircraft.

Table 1. Participating Flight Simulator Types, Sponsoring Facilities, and Locations

SIMULATOR TYPE	SPONSORING FACILITY and LOCATION
1. B747-400	NASA-Ames, Moffett Field, CA
2. MD90	Delta Airlines Inc., Atlanta, GA
3. B727	AVIA Inc., Costa Mesa, CA
4. B727	Mike Monroney Aeronautical Center, Oklahoma City, OK
5. GAT	William J. Hughes Technical Center, Atlantic City International Airport, NJ

The test team determined the type of approach flown by pilots of the flight simulators (i.e., coupled autopilot, hand-flown using the flight director, raw data) based upon surveys of current airline procedures. For simulators that were glass cockpit/FMS-equipped (NASA B747-400, Delta MD90), the test team instructed the crews to fly coupled autopilot approaches 80% of the time and hand-fly using the flight director 20% of the time. For analog/conventional simulators (AVIA B727, Oklahoma City B727), the test team instructed the crews to fly coupled autopilot approaches 50% of the time and hand-fly using the flight director 50% of the time. The test team instructed the crews flying the GAT to fly coupled autopilot approaches 5% of the time, hand-fly using the flight director 45% of the time, and fly using raw data 50% of the time.

The researchers incorporated crosswinds into the flight simulator approaches to provide pilots with a realistic flight environment. Three direct crosswind conditions were assigned throughout the scenarios: no wind, a 15-kt wind from the east, and a 15-kt wind from the west. All flight simulators were assigned the same wind condition for any given run.

2.4 Simulation Instruments

2.4.1 Traffic Samples

The MPAP test team generated four traffic samples for the simulation based on a survey of instrument operations for several level 5 (i.e., airports that have 100 or more instrument operations per hour) terminal radar approach control (TRACON) facilities. Traffic samples contained lists of all the aircraft arrivals, which included call signs, beacon codes, aircraft types, and start times for entering the traffic scenarios. Approximately 65 aircraft per runway entered the simulation scenario per 2-hour run. The traffic samples also contained departing aircraft to generate a more realistic ATC environment. Approximately 60 aircraft per runway per 2-hour run were departures.

A representative number of air carriers (65%), commuters (30%), and general aviation aircraft (5%) targets constituted the traffic mix. Air carriers (jets) and commuters (turboprops) were assigned initial indicated airspeeds (IASs) of 180-200 kts. General aviation aircraft (props) were assigned initial IASs of 130-150 kts. Speed overtakes were not intentionally scripted into the traffic samples; however, overtakes did randomly occur throughout the simulation, and monitor controllers had to make speed adjustments when necessary.

2.4.2 Blunder Scripts

The test team developed traffic samples not only to generate traffic for the simulation but also to determine when aircraft would be aligned for potential conflicts. They devised them prior to the simulation and observed them on the radarscopes to determine the call signs of adjacent aircraft targets and the times of potential conflicts. This information was recorded to generate blunder scripts. The blunder scripts noted aircraft pairs, along with the response conditions and blunder paths for the test director to use during simulation runs.

2.4.3 Closest Point of Approach Prediction Tool

The Closest Point of Approach (CPA) prediction tool is a software tool used by the test director during MPAP simulations to create potential at-risk blunders. The CPA is defined as the smallest slant range distance between two aircraft involved in a conflict. The tool uses aircraft velocities, headings, and degree of turn for each aircraft pair in the real-time calculation of a predicted CPA. The tool also calculates the elapsed time until the predicted CPA is reached, given an immediate execution of a blunder. All of the CPA prediction tool information is updated every second.

During this simulation, the CPA prediction tool presented call signs of predetermined potential blunder aircraft pairs in a window on the test director's display. The window could accommodate information on eight aircraft pairs at a time. The blunder scripts determined the aircraft pairs, which appeared in the window; however, the test director had the capability to delete scripted aircraft pairs and/or add pairs that were not originally included on the blunder scripts.

2.5 Subjects and Training

2.5.1 Final Monitor Controllers

A total of 12 ATC Specialists with experience in simultaneous parallel approach operations participated in the simulation. Controllers were selected from the following TRACON facilities: Pittsburgh, St. Louis, Denver, Nashville, Charlotte, Baltimore, and Cincinnati. All controllers were volunteers selected in agreement with their National Air Traffic Controllers Association offices.

Controllers were each scheduled to participate in one of two groups. Both groups had an equal amount of practice the first week. During the test week, the first group of six participated in eight runs, April 22-24, and the other group participated in seven runs, April 24-26. Individual controllers were scheduled to work as monitor controllers for one hour each per 2-hour run. A controller rotation period occurred at the midpoint of each 2-hour run to simulate actual work rotations and to give monitor controllers a rest. Controllers were not scheduled to participate in more than three runs on any day of the simulation.

2.5.1.1 Controller Briefing

The MPAP test team briefed the controllers prior to participating in the simulation. The briefing included a description of the MPAP TWG's composition and program goals. They also explained the simulation, followed by a presentation of a PRM video to familiarize controllers with the components of the PRM system. The briefing package included diagrams of the simulated airport approach area configuration and the approach plates that were contained in the pilot briefings. Controller schedules of participation were also included. Appendix D contains the complete briefing as distributed to the test controllers.

The primary focus of the briefing package was on controller responsibility. Controllers were given an overview of the responsibilities of the final monitor controller, as prescribed in FAA Order 7110.65 (FAA, 1996a). Controllers were told not to make speed adjustments to aircraft inside the final approach fixes (FAFs) and were reminded of the monitor controller's override capabilities on the local control frequencies.

The instructor read a paragraph from the Airman's Information Manual (FAR, 1996) to the controllers that stated that the primary navigation responsibility was to rest with the pilot. Aircraft that were observed to enter the NTZ, however, were to be instructed to alter course left or right, as appropriate, to return to the desired courses.

Controllers were instructed to use the following phraseology in the event that an aircraft overshot the turn-on or continued on a flight path that would penetrate the NTZ:

- "You have crossed the final approach course. Turn (left/right) immediately and return to the localizer/azimuth course," or
- "Turn (left/right) and return to the localizer/azimuth course."

Controllers were instructed to use the following phraseology if an aircraft on an adjacent approach was in potential conflict with a deviating aircraft:

> TRAFFIC ALERT (TA), aircraft call sign, turn (left/right) immediately heading (degrees),
>
> climb and maintain (altitude). (FAA Order 7110.65 Change as of 1/10/97, FAA, 1996a).

In addition, controllers were instructed to use the following standard breakout headings and altitudes, whenever feasible, for aircraft on adjacent courses to deviating aircraft:

- Runway 18R: Turn right immediately heading two seven zero, climb and maintain six thousand.
- Runway 18C: [No standard heading and/or altitude.]
- Runway 18L: Turn left immediately heading zero niner zero, climb and maintain five thousand.

The standard altitudes were increased from the August 1995 to the April 1996 triple approach simulation. In August 1995, standard altitudes for both runways 18R and 18L were 4,000 feet. They were raised for the April 1996 simulation to 6,000 feet for 18R and 5,000 feet for 18L to avert a situation where a controller would have to issue descending breakout instructions to an endangered aircraft prior to the outer marker.

2.5.1.2 Controller Training

Controllers were given hands-on training with the PRM equipment following the briefing and prior to actual test runs. Each group of controllers rotated through monitor positions over the course of eight 2-hour practice runs. The purpose of the training was to familiarize the controllers with the FMA displays and to expose them to blunder situations. Controllers were encouraged to practice the standard phraseology and to coordinate actions with other monitor controllers during blunders.

2.5.2 Pilots

A total of 37 pilots participated in the simulation. Of these, 31 were air carrier pilots with an average of 10,861 total flight hours and 6 were general aviation, military, or commuter pilots with an average of 1,917 total flight hours. Air carrier pilots that participated in the simulation were required to be qualified and current on the type of aircraft represented by the simulator to which they were assigned. Pilots who flew the GAT were required to hold at least commercial flight certificates with multi-engine and instrument ratings.

Three pilots were assigned to each air carrier flight simulator site each day, except at the National Aeronautics and Space Administration (NASA) facility where two pilots flew together the entire day. Single pilot Instrument Flight Rules (IFR) operations were conducted at the GAT; therefore, two pilots divided the flying time each day. Each pilot flew approximately eight approaches in the air carrier simulators and approximately 10 approaches in the GAT each day.

2.5.2.1 Pilot Briefing and Training

Pilots reported to their respective simulator sites 1 hour before the start of the simulation for training. After reviewing a Pilot Briefing Handout (Appendix E), pilots were shown a 12-minute video entitled RDU Precision Runway Monitor: A Pilot's Approach (FAA, 1995). Following the video, all pilots reviewed simultaneous close parallel approach plates and an airport information page (Appendix F). Air carrier pilots were required to read a Pilot Awareness Training Bulletin (Appendix E) and take a self-administered test to reinforce what they had read. Air carrier pilots assigned to the glass cockpit simulators (i.e., B747-400 and MD90) were required to read a Breakout Procedure Bulletin and take a self-administered test on the material (Appendix E). This bulletin presented a hand-flown aircraft breakout procedure that emphasized turning off the flight director of the pilot flying until the pilot not flying changed the flight director display to conform with the breakout instructions. To emulate annual recurrent training, pilots who participated in a previous simulation and were trained within 12 months of the current simulation did not have to be retrained. Table 2 depicts the training pilots received by site.

Table 2. Pilot Training by Simulator Site

Simulator Site and Type	RDU Video	Pilot Awareness Bulletin and Test	Procedure Bulletin and Test
1. GAT	X		
2. AVIA, B727	X	X	
3. OKC, B727	X	X	
4. DELTA, MD90	X	X	X
5. NASA, B747-400	X	X	X

This training session was designed to be similar to what a pilot could encounter at an airline. After reporting for work, the pilot would find the training bulletins in his or her mailbox along with self-administered tests. The pilot would read the bulletins, complete the tests, and hand them in to the chief pilot. Then the pilot's training records would be updated accordingly. General aviation pilots were only required to view the video. The Pilot Briefing Handout, the Pilot Awareness Training Bulletin, the Breakout Procedure Bulletins, and the corresponding self-administered tests are located in Appendix E.

2.5.2.2 Pilot Briefing Materials

2.5.2.2.1 Approach Information Index Cards

Prior to each approach, an on-site researcher handed the pilots an Approach Information Index Card to place on the cockpit console. These cards provided simulator pilots, site coordinators, and technicians with the necessary details to insure that the simulators had been set up correctly. The following information was included on the index card:

a. runway,

b. type aircraft represented,

c. time at which the aircraft was scheduled to enter the simulation,

d. aircraft call sign (located in center of card, in large font for ease of recognition),

e. initial heading to fly,

f. initial altitude,

g. initial IAS,

h. localizer frequency,

i. tower frequency,

j. transponder code,

k. method of flying the approach (autopilot coupled, handflown using flight directo,r or hand-flown using raw data),

l. traffic sample number,

m. simulator site, and

n. index number.

2.5.2.2.2 Approach Plates and Airport Information Page

Pilots used approach plates designed specifically for simultaneous close parallel approaches, along with an airport information page. The approach plates differed from those used for normal ILS approaches in that they included information designed to heighten pilot awareness of close parallel ILS operations. Two notes were placed in the plan view section of the approach plates. The first note authorized simultaneous close parallel approaches with the adjacent runway and stated that radar and glideslope were required. The second note required the pilot to read the airport information page before flying the close parallel approach. In the heading section of the approach plates, under the procedure identification of "ILS PRM Rwy 18X," the words "Close Parallel" appeared in parentheses.

The airport information page contained an illustration of the centerline spacing between runways, the pilot requirements for flying the simultaneous close parallel approach, a paragraph on breakout descents, a section on controller phraseology, and an emphasis on the importance of an immediate pilot response to a controller's breakout instructions. The approach plates and airport information page are located in Appendix F.

2.5.2.2.3 Automatic Terminal Information System Cards

The MPAP test team provided the pilots with cards containing an Automatic Terminal Information System (ATIS) script during the simulation. These cards represented the ATIS broadcast the pilots would listen to before entering the airport environment. The cards contained ceiling, visibility, restrictions to visibility, temperature, dewpoint, wind, altimeter setting, approaches in use, and an ATIS single letter identifier. The approaches in use were listed as "simultaneous close parallel ILS runways 18L, 18C, and 18R." Three separate cards were used to reflect the changing wind conditions used in the simulation. The MPAP test team identified these cards as information Alpha, information Bravo, and information Charlie, respectively. Appendix E contains an example of an ATIS card.

2.6 Experimental Design

2.6.1 Experimental Factors Description

The test team scripted all blundering aircraft in the simulation to have certain response conditions (i.e., responding or non-responding) and blunder paths (i.e., maintain altitude or descend). In addition, they distributed the blunders along the localizer courses and initiated them towards certain types of aircraft according to predetermined percentages.

2.6.1.1 Response Condition

To simulate worst-case situations where blundering aircraft were unable to correct their deviations, the test team often instructed the pilots of blundering aircraft to disregard controller communications, thereby not correcting the blunder. They referred to this type of blunder as non-responding. The team scripted 80% of all blundering aircraft over the course of the simulation to be non-responding.

2.6.1.2 Blunder Path

For additional realism, the test team scripted the paths of blundering aircraft to either maintain altitude or descend on a 3-degree glidepath. They scripted 50% for each condition.

2.6.1.3 Blunder Distribution along Localizer Course

For purposes of tracking where blunders occurred along the localizer courses, the test team categorized, or "binned", distances from the runway thresholds into the following groups: 1-3 nm, 3-5 nm, 5-7 nm, 7-9 nm, 9-12 nm, and 12-15 nm. Their goal was to have 20% of the blunders occur in the 1-3 nm and 3-5 nm bins, 15% in the 5-7 nm and 7-9 nm bins, 20% in the 9-12 nm bin, and 10% in the 12-15 nm bin.

2.6.1.4 Aircraft Types and Flight Systems

Blunders were also initiated according to predetermined traffic mix percentages based upon aircraft types and flight systems. Table 3 summarizes the blunder initiation traffic mix percentage goals. See Appendix G for a summary of all of the simulation distribution goals and actual results.

Table 3. Blunder Initiation Goals for Aircraft Types and Flight Systems

	Flight Simulator	Goal (percent)
Evading Aircraft Type		
Heavy Jet	B747-400	30
Jet	B727s, MD90	60
General Aviation	GAT	10
Evading Aircraft Flight System		
Glass	B747-400, MD90	50
Analog/Conventional	B727s	40
General Aviation	GAT	10

2.6.2 Performance Measures

Dependent variables in the simulation included CPA, frequency of NTZ entries, and frequency of NBOs.

2.6.2.1 Closest Point of Approach

The MPAP test team measured blunder resolution performance by determining the proportion of successfully resolved conflicts relative to the total number of blunders that would have resulted in TCVs had there been no controller intervention. They examined the resolution of conflicts by calculating CPAs. The CPA was the smallest slant range distance between two aircraft involved in a conflict (measured in ft). The researchers measured distance every second from the center of each aircraft involved in the conflict.

2.6.2.2 Frequency of No Transgression Zone Entries and Nuisance Breakouts

The test team determined the number of NTZ entries and NBOs and used them as a measure of system capacity. They computed the frequencies of NTZ entries and NBOs through a review of PRM video and audio recordings of each run of the simulation.

2.7 Procedure

Controllers staffed three final approach monitor positions. Their tasks included monitoring the flight paths of the aircraft on their assigned runways. Aircraft blunders were initiated to test the ability of the ATC system to maintain the 500-ft miss distance criterion between aircraft during critical situations. During each run of the simulation, blunders occurred without warning to the controllers. During blunder events, controllers issued control instructions to attempt to resolve the situations.

Blunder scripts, traffic samples, and the CPA prediction tool guided the initiation of the blunders. Approximately 10 blunders were scripted per 2-hour run. Blunders did not occur within less than 3 minutes of each other or within 1 nm of the runway thresholds. All blundering aircraft were TGF aircraft and nearly all evading aircraft were flight simulators.

2.8 Support Personnel

2.8.1 Test Director

A simulation test director initiated simulation runs and aircraft blunders. Individuals who assumed the role of test director had extensive ATC experience and were trained to work with the CPA prediction tool. The test director was responsible for initiating blunders based upon the information provided by the blunder scripts, the CPA prediction tool, and his expert judgment.

2.8.2 Controller Technical Observers

Five controller technical observers participated in the simulation, all of whom had ATC experience and were familiar with the MPAP project. Controller technical observers monitored controller actions during each simulation run. Their tasks included documenting discrepancies between issued control instructions and actual aircraft responses, alerting responsible parties to any problems that may have occurred during the test (e.g., computer failure, stuck microphone), assisting controllers with the preparation of blunder statements, and preparing a controller technical observer assessment at the end of the simulation. The assessment included their opinions and conclusions concerning the conduct of the simulation as well as any recommendations to the MPAP TWG.

2.8.3 Simulation Pilot Operators

SPOs operated the TGF aircraft during simulation runs. They controlled blundering aircraft at the instruction of the test director and responded to controller instructions (except during non-responding blunders) by entering aircraft heading and/or altitude changes using their specialized computer keyboards and displays.

2.8.4 Tower Controllers

To add realism to the communications on the final monitor frequencies, six non-subject tower controllers rotated through performing local tower control functions. They cleared aircraft for departure and landing and advised frequency changes.

2.8.5 Site Coordinators

Site coordinators participated at each flight simulator location to coordinate efforts with the test director at the William J. Hughes Technical Center and to support pilots during their participation in the simulation. The MPAP test team provided them with a Site Coordinator Briefing Materials package that detailed their duties and responsibilities. Site coordinators included current or retired airline pilots for each air carrier type simulator and one certified flight instructor for the GAT. All site coordinators had experience with MPAP real-time simulations and with the type of aircraft represented by the flight simulator to which they were assigned.

Site coordinators acted as observers and did not provide any help to the aircrews that would invalidate the simulation data. Their responsibilities included briefing aircrews, providing pilots with flight information prior to each approach, documenting approach information, and administering questionnaires to the pilots. The Site Coordinator Briefing Materials are located in Appendix H.

2.8.6 Simulation Observer

A simulation observer manually documented information from the test director's station, including blunder occurrences, NBOs, NTZ entries, potential TCVs, lost beacon signals (i.e., aircraft that went into coast, indicating a loss of radar tracking), and system problems (e.g., communications failure, hardware/software failure).

2.9 Data Collection

2.9.1 Computer-Generated Data Files

The generation of data files by the TGF allowed for a detailed examination of the performance of the ATC system in resolving blunders. Data files included information on parallel conflict frequencies, parallel conflict slant range CPAs, and aircraft position/track data.

Flight simulators also generated data files. These files contained detailed information about the simulator aircraft performance, including angle of bank, rate of climb, and pitch angle, allowing detailed analysis of pilot/aircraft responses.

2.9.2 Audio and Video Recordings

The MPAP test team recorded all communication frequencies and visual components of the PRM display for each run on a Super-VHS videocassette recorder. A 20-channel DICTAPHONE audio recorder and a 9-channel IONICA audio recorder provided backup audio recordings. Both the DICTAPHONE and the IONICA systems operated with an AMECOM system and independently of one another and of the TGF operating system.

The test team set up video cameras in all flight simulators to capture the interactions between the pilots in the cockpit and between pilots and controllers. In addition, they mounted a video camera behind the controllers in the monitor room to capture all interactions and coordinating efforts between controllers during blunders and other events in the simulation.

The test team used the videotapes for the examination of TCVs, the evaluation of controller phraseology and other message characteristics, the extraction of controller and pilot response times, the identification of NTZ entries and NBOs, and the verification of computer-generated data file information.

2.9.3 Questionnaires

2.9.3.1 Controller Questionnaires

Controllers received Blunder Statement Questionnaires during the simulation if the controller technical observers believed a TCV occurred while those controllers were on position. Controllers were instructed to describe the conflict in detail on the Blunder Statement. They also completed a Post-Simulation Questionnaire at the conclusion of their participation in the simulation. The Post-Simulation Questionnaire addressed issues such as the operational viability of the runway configuration, the degree of communications workload, and simulation realism. The controller questionnaires are found in Appendix I.

2.9.3.2 Pilot Questionnaires

Site coordinators administered two different questionnaires to pilots during the simulation. After every breakout, they issued a Pilot Breakout Questionnaire, which was used to evaluate the breakout from initial controller transmission until the scenario had ended. Second, pilots completed a Flight Crew Opinion Survey at the conclusion of their participation in the simulation. The Flight Crew Opinion Survey took advantage of subject pilot expertise and collected subjective data on the adequacy of the training materials, approach plates, information page, and breakout instructions. Appendix J contains both pilot questionnaires.

2.9.4 Observer Logs

Controller technical observers and site coordinators recorded information on logs during the simulation. In general, the test team instructed the controller technical observers to capture information pertaining to blunders, potential TCVs, NBOs, NTZ entries, and simulation problems to be used in conjunction with the computer-generated data. The test team instructed the site coordinators to record approach and breakout information, such as approach identification, simulator problems, approach abnormalities, answers to the Pilot Breakout Questionnaires, and comments from the observer or the pilot concerning the approach.

3. Simulation Results

It should be kept in mind that the results of this study should not be extrapolated to situations that contain variables other than those tested in this study.

3.1 Assessment Methodology

The MPAP test team used all data-collection sources, including computer-generated data, video and audio data, pilot and controller questionnaires, and observer logs to evaluate the proposed operation performance in meeting the established test criteria.

The test team only used data from blunders involving flight simulators as evading aircraft in the blunder resolution performance and NTZ entry analyses. This is due to aerodynamic performance differences that have been identified between TGF aircraft and flight simulators. The TGF interface does not enable SPOs to respond in a manner that is representative of operational aircraft. In addition, SPOs are not actual line pilots. The NBO analysis included both flight simulator and TGF aircraft because TNSE usually caused NBOs, and the fidelity of the pilot/aircraft performance was not as critical as in the blunder resolution performance. The ASAT Monte Carlo computer simulation of parallel approach blunders used the real-time simulation data to enhance the risk assessment part of the analysis. The test condition parameters were the same as for the real-time simulation. The Monte Carlo analysis used the recorded controller and aircraft response data as inputs to the models. The test team compared the Monte Carlo TCV rate results to the real-time TCV rate results to ensure they were compatible. Appendix C describes the risk assessment methodology.

In addition to the data available from the simulation, the MPAP TWG drew upon their understanding of the nature of daily operations, the knowledge and skills of controllers and pilots, and the full range of traffic contingencies to evaluate the pilot and controller communications workload and to develop their operational assessment of the proposed operation.

3.2 Test Criterion Violation Review

Three TCVs occurred in the real-time simulation. The following is a summary and the actual sequence of events for each TCV.

3.2.1 TCV 1

The first TCV resulted when a controller issued the wrong call sign to an aircraft during the evasion instruction. The controller called "TWA Two-Twenty" instead of the correct call sign, TWA One-Twenty. The pilot not flying immediately questioned the controller, "TWA One-Twenty?" Three seconds after call sign and instruction verification was received, the pilot flying began the breakout. The blundering and evading aircraft, however, did not maintain adequate separation. The controller was also determined to be slow in responding. The yellow alert occurred 5 seconds before the controller took any action. This TCV had a CPA of 450.55 ft.

Sequence Of Events:

0:07:20	*Blunder Start*	
0:07:28	*Yellow Alert*	
0:07:33	**Evader Controller Begin #1**:	"Traffic Alert, TWA Two-Twenty, turn right immediately heading two-seven-zero, climb and maintain six thousand."
0:07:36	*Red Alert*	
0:07:40	**Evader Controller End #1**	
0:07:42	Evading A/C Pilot Begin:	"TWA One-Twenty?"
0:07:43	Evading A/C Pilot End	
0:07:43	**Evader Controller Begin #2**:	"Traffic Alert, TWA One-Twenty, turn right immediately, climb and maintain six thousand."
0:07:47	**Evader Controller End #2**	
0:07:48	Evading A/C Pilot Begin:	"Four for six, two-seven-zero, United, uh, TWA One Twenty."
0:07:52	Evading A/C Pilot End	
0:07:52	**Evader Controller Begin #3**:	"Expedite your climb, TWA One-Twenty, traffic off your left about two hundred feet, same altitude."
0:07:57	**Evader Controller End #3**	
0:08:01	**CPA**	
0:08:16	**Evader Controller Begin #4**:	"TWA One-Twenty, the traffic's no factor, diverging now, climb and maintain six thousand."
0:08:20	**Evader Controller End #4**	

0:08:21	Evading A/C Pilot Begin:	"TWA One-Twenty."
0:08:22	Evading A/C Pilot End	

3.2.2 TCV 2

The controller's issuance of non-standard breakout phraseology to the evading aircraft attributed to the second TCV. The prescribed standard breakout phraseology included both a heading and an altitude instruction in one transmission. The purpose of one transmission was to expedite the breakout maneuver and also to reduce the possibility of blocked communications occurring between multiple transmissions. During this blunder event, the controller instructed the evading aircraft to turn right immediately and then he ended his transmission. The aircraft verbally responded. The controller then instructed the aircraft to climb in a second transmission. At that time, there was also some confusion in the cockpit as to whether the crew was supposed to maintain their altitude, which was 5,000 ft, or descend to 4,000 ft. They questioned the controller if they should descend and the controller responded, "Affirmative." At that time, it was too late. The two aircraft came within 385.99 ft of each other and therefore a TCV occurred.

Sequence Of Events:

0:17:24	*Blunder Start*	
0:17:29	*Yellow Alert*	
0:17:34	**Evader Controller Begin #1**:	"Traffic Alert, American Two-Twenty-Five,
0:17:35	*Red Alert*	turn right immediately heading two-seven-zero."
0:17:39	**Evader Controller End #1**	
0:17:40	Evading A/C Pilot Begin:	"Two-seven-zero, American Two-Twenty-Five."
0:17:42	Evading A/C Pilot End	
0:17:43	**Evader Controller Begin #2**:	"American Two-Twenty-Five, maintain... four thousand."
0:17:45	**Evader Controller End #2**	
0:17:46	Evading A/C Pilot Begin:	"American Two-Twenty-Five, we're at five now, descend to four."
0:17:49	Evading A/C Pilot End	
0:17:49	**Evader Controller Begin #3**:	"Affirmative, there's traffic right above you at fifty-seven, a Seven-Fifty-Seven."
0:17:52	**Evader Controller End #3**	
0:17:58	**CPA**	

3.2.3 TCV 3

The aircrew did not clearly understand part of the controller breakout instruction, which attributed to the third TCV. The result was a delayed response by the flight crew. The controller instructed United 274 to turn to a certain heading and climb to a certain altitude. The pilots responded by verifying the altitude and questioning the heading instruction. The controller repeated the heading and instructed the aircraft to respond without delay. The pilot flying did not perform an aggressive turn but was still able to begin the breakout maneuver 12 seconds from the first "Traffic Alert." Nevertheless, a TCV resulted. The CPA was 215.53 ft. The Captain remarked that flying the center approach contributed to some confusion as to which way to turn, which prompted the request for heading confirmation.

Sequence of Events:

1:42:25 *Blunder Start*	
1:42:(29) 31 *Yellow Alert*	
1:42:33 **Evader Controller Begin #1**: 1:42:36 *Red Alert*	"Traffic Alert, United Two-Seventy-Four, turn left immediately heading one-two-zero, climb and maintain six thousand."
1:42:39 **Evader Controller End #1**	
1:42:41 Evading A/C Pilot Begin:	"That was up to six thousand and left to what heading for United Two-Seventy-Four?"
1:42:45 Evading A/C Pilot End	
1:42:45 **Evader Controller Begin #2**:	"United Two-Seventy-Four, turn left heading one-two-zero, no delay in the left turn, traffic off your right departed the parallel localizer."
1:42:50 **Evader Controller End #2**	
1:42:51 Evading A/C Pilot Begin:	"One-two-zero."
1:42:52 Evading A/C Pilot End	
1:42:56 **CPA**	

3.3 Test Criterion Violation Rate and Risk Analyses

The test team performed two analyses to estimate the TCV rate. First, they used the real-time simulation data to calculate an at-risk TCV rate. Then, they performed a fast-time, Monte Carlo simulation, using the ASAT, to increase the sample size. They based the Monte Carlo simulation on data extracted from the real-time simulation and provided a more accurate estimate of the TCV rate. The researchers determined the confidence intervals for each of the TCV rates and compared them to the test criterion rate of 5.1%. The following sections discuss these analyses.

3.3.1 Real-Time Simulation

Out of a total of 154 blunders that occurred in the real-time simulation, the test team considered 146 at-risk. Of those at-risk blunders, 125 were non-responding and 21 were responding. The observed TCV rate was 2.4% (3 TCVs/125 at-risk, non-responding blunders). The 99% confidence interval was 0.272 to 8.506%. Although the observed TCV rate, 2.4%, was below the test criterion of 5.1%, the upper-confidence limit was larger than the test criterion. Therefore, they consider the results of the real-time simulation for the three runways to be inconclusive.

Analysis of the real-time simulation data indicated that 67 at-risk WCBs occurred within the 4,000-ft spaced pair of adjacent runways. Of those, two resulted in TCVs. The observed TCV rate was 2.985%. The lower-confidence limit was 0.156%, and the upper-confidence limit was 13.112%. The maximum allowable TCV rate for dual approaches is 6.8%, and because 6.8% is between 2.985% and 13.112% the result of the real-time simulation risk assessment for the 4,000-ft spaced pair of adjacent runways is also inconclusive.

Analysis of the real-time simulation indicated that 58 at-risk WCBs were simulated using the 5,300-ft spaced pair of adjacent runways. Of those, one resulted in a TCV. The observed TCV rate was 1.724%. The lower-confidence limit was 0.00864%, and the upper-confidence limit was 12.123%. The maximum allowable TCV rate for dual approaches is 6.8%, and because 6.8% is between 1.724% and 12.123% the result of the real-time simulation risk assessment for the 5,300-ft spaced pair of adjacent runways is also inconclusive. Therefore, the analysis of the real-time simulation is inconclusive, and it is necessary to rely on the Monte Carlo simulation for resolution of the problem.

3.3.2 Monte Carlo Simulation

The following sections report the results of the ASAT Monte Carlo simulation and how they compared to the maximum acceptable TCV rate. For details on the ASAT model configuration, see Appendix B.

3.3.2.1 ASAT Results

The ASAT Monte Carlo simulation executed 100,000 at-risk non-responding blunders with 30% heavy jets that resulted in a TCV rate of 0.899%. The 99% confidence interval was 0.824 to 0.979%. The ASAT Monte Carlo TCV rate was also below the test criterion maximum TCV rate of 5.1%.

The ASAT TCV rate was also calculated for the two proximate pairs of runways. The 18C runway and the 18R runway were separated by 4,000 ft. The TCV rate for this pair of runways, with 30% heavy jets, was 1.796% with a lower-confidence limit of 1.647% and an upper-confidence limit of 1.955%. The 18C runway and 18L runway were separated by 5,300 ft. The TCV rate for this pair of runways was 0.002% with a lower-confidence limit of 0.00001% and an upper-confidence limit of 0.0149%. This indicates, as expected, that the TCV rate is highly dependent on runway spacing. The ASAT Monte Carlo TCV rate and the upper confidence limit for the TCV rate were both less than the test criterion of 5.1%. Each of the confidence intervals from the Monte Carlo simulation intersected its corresponding confidence interval from the real-time simulation; therefore, the result of the Monte Carlo simulation was consistent with the result of the real-time simulation.

3.4 No Transgression Zone Entry and Nuisance Breakout Analyses

Flight simulators did not make any NTZ entries that were not the result of a blunder or a breakout. Therefore, the NTZ entry rate was acceptable.

A total of 5 NBOs occurred in the real-time simulation out of the 2,586 non-blunder-related approaches (0.2%). The TWG and technical observers agreed that the NBO rate was at an acceptable level.

3.5 Controller Communications Workload

Participating controllers, controller technical observers, and the TWG deemed the controller communications workload associated with TNSE-related events for the proposed operation was satisfactory. The number of NTZ entries and NBOs was not excessive; therefore, controllers were not overburdened with communications to aircraft flying the approaches.

3.6 Technical Work Group Operational Assessment

Based upon the test results, the TWG expertise and judgment, and evaluations from the controller technical observers, the TWG unanimously agreed that the procedure met all of the established criteria. The enhanced controller training procedures, including 8 hours of hands-on training with the PRM system and improved controller breakout phraseology, and the pilot training clearly contributed to the success of the proposed operation.

Controllers were better trained on the use of the breakout phraseology and on the use of the FMA displays than in the previous triple approach simulation. The enhanced training procedures and phraseology affected overall system performance so that they clearly understood responsibilities, improved response times, and maintained adequate aircraft separation.

The TWG unanimously agreed to recommend the tested procedure on simultaneous approaches to three runways spaced 4,000 and 5,300 ft apart using the PRM system with a 1.0 second update rate for approval in the operational environment.

3.7 Additional Analyses

The TWG had additional data available to refer to as necessary when evaluating the four test criteria. The following sections describe in detail the supplemental assessments and analyses that were performed.

3.7.1 Controller Technical Observer Assessment

During the simulation, the controller technical observers witnessed improvements in controller performance from the previous triple approach simulation. The controller technical observers attributed the success of the simulation to several controller-training modifications, as follows:

1) The lengthened, mandatory 8 hours of time on position prior to actual test runs enabled controllers to become familiarized with the PRM equipment and to practice detecting and resolving blunders;

2) The shortened phraseology (i.e., the elimination of the first aircraft call sign at the beginning of the message) allowed for an easier delivery of instructions to endangered aircraft. Controllers were not preoccupied with the wording of the breakout

instructions, but rather could focus their efforts on getting the instructions out in timely manners and conveying the urgency of the situations to the aircrews;

3) The controller briefing emphasized the importance of issuing the entire breakout instruction in one transmission, and throughout the simulation they completed most instructions in one transmission;

4) The standard breakout altitudes were raised, which minimized the necessity for pilots to execute a descending breakout maneuver. This appeared to facilitate a quicker breakout due to inherent climb function of the autopilot go-around feature and the familiarization of the pilot to this operation.

After observing this simulation, the controller technical observers concluded that the 4,000- and 5,300-ft simultaneous triple approach procedure could be conducted safely and efficiently in the operational environment. The intent of the controller training requirements was not for simulation purposes only, but is to be a prerequisite at all facilities who are planning to implement this triple approach procedure. Therefore, the effects of the training in the simulated environment showed promising results as to what should occur in the operational environment upon approval of the procedure.

3.7.2 Closest Point of Approach Distribution Analyses

The distribution of CPAs over the course of the simulation was examined to provide information on the degree of separation maintained for all WCBs involving flight simulators. Figure 5 shows that the mean separation for WCBs was 2,016.16 ft, with a standard deviation (SD) of 847.56 ft. The range of CPAs was from 215.53 ft to 4,516.01 ft. CPAs were also sorted by simulator type and examined. Table 4 details the results.

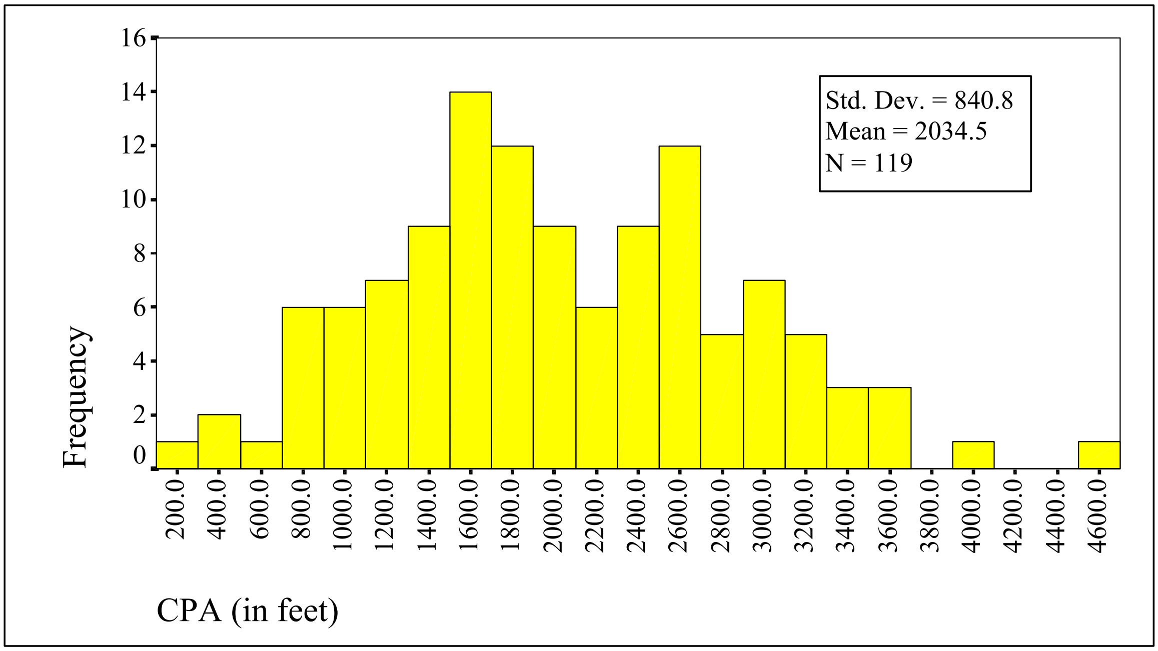


Figure 5. Closest point of approach distribution for all WCBs.

Table 4. CPA by Simulator Type

SITE	SIMULATOR TYPE	MEAN CPA (ft)	STANDARD DEVIATION (ft)	NUMBER OF CASES
AVIA	B727	2,462.77	925.41	25
DELTA	MD90	1,991.45	663.25	29
GAT	C421	1,849.76	769.54	8
NASA	B747-400	1,748.10	901.43	34
OKCITY	B727	2,110.87	730.74	23

3.7.3 Controller Response Time Analyses

The test team determined the controller response times from the blunder data. Of 150 blunders, they could not extract response times from 3 blunders. They calculated response times from the time of the alert onset (i.e., the change in color of the predictor line and data block from green to yellow) to the time the controller keyed the microphone to communicate with the pilot of the evading aircraft. Response times ranged from -3 seconds to 9 seconds. The mean response time for all blunders was 1.7 seconds with an *SD* of 1.9 seconds. In the Monte Carlo simulation, they only used response times greater than 1.0 second collected from the real-time simulation. Figure 6 depicts the complete frequency distribution of controller response times, which were independent of blunder range from threshold.

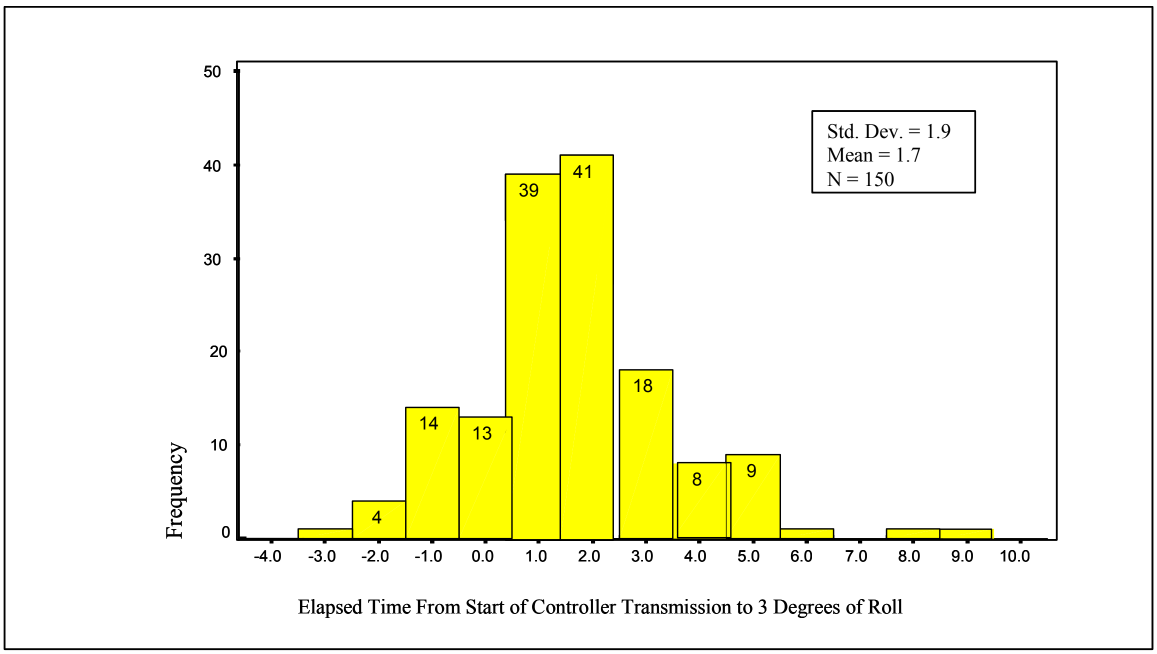


Figure 6. Controller response times for all blunders.

3.7.4 Pilot/Aircraft Response Time Analyses

Pilot/aircraft response times for the evaders were extracted using data collected at the flight simulator sites. The pilot/aircraft response was measured as elapsed time from the beginning of the evader controller transmission to a particular event (e.g., attainment of 3 degrees of roll, increase in engine pressure ratio). This analysis focuses on the time to attainment of 3 degrees of roll because the promptness of the turning response appears to be the most critical in assuring separation of aircraft during a blunder scenario. The distribution of roll response times for the simulation, in seconds, is shown in Figure 7.

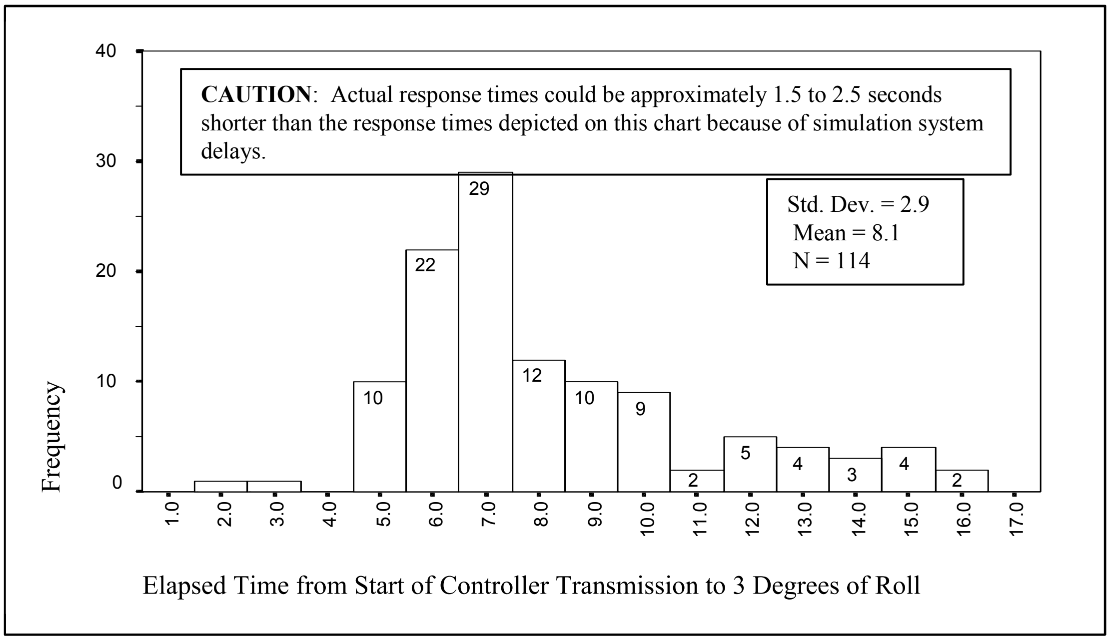


Figure 7. Roll response times for all flight simulator sites for all blunders.

NOTE: During post-simulation analyses, the MPAP test team noted that the pilot/aircraft response times observed in the cockpit simulator videotapes appeared to be 2 to 3 seconds faster than the response times derived from the automated data. Initial investigation revealed a delay in the data (both time and position) on the PRM display, most likely due to delays in the network and the simulated PRM. Further investigation is necessary to confirm the source(s) of the delays and to find more precise figures for them; however, one can consider the results of the simulation to be conservative. The pilot/aircraft responses in this section have not been adjusted for the delays, but could be approximately 1.5 to 2.5 seconds less than the times indicated (0.5 seconds was subtracted from 2 to 3 seconds because the specifications of the production system include a maximum delay of 0.5 seconds).

Data for the roll response times (times to attainment of 3 degrees of roll) were available for most of the evasions with the exception of 6 out of 30 from the AVIA site, 21 out of 37 from the Delta site, 5 out of 13 from the GAT site, 5 out of 44 from the NASA site, and 2 out of 30 from the Oklahoma City site.

As can be seen in the figure, approximately 65% of the roll response times were less than 8.5 seconds. Further, the data indicated only small differences among the flight simulator sites. A breakdown of roll response time statistics by simulator site is shown in Table 5.

Table 5. Roll Response Time Statistics by Simulator Site

CAUTION: Actual response times could be approximately 1.5 to 2.5 seconds shorter than response times depicted on this chart because of simulation system delays.

	AVIA B727	Delta MD90	GAT	NASA B747	OKC B727	All Sites
Median Time to 3 Degrees Roll	6.3	7.7	6.0	8.1	7.0	7.0
Mean Time to 3 Degrees Roll	7.0	8.9	6.3	8.8	8.2	7.8
Minimum Time to 3 Degrees Roll	5.0	6.6	3.4	5.2	2.2	4.5
Maximum Time to 3 Degrees Roll	14.5	16.3	11.7	15.2	15.6	14.7
Number of Breakouts	24	16	7	40	27	114

3.7.5 Controller Breakout Instruction Content Analyses

The test team studied all controller breakout instructions made during the simulation in detail for content and quality of delivery. Two components of the messages that the researchers analyzed were use of standard phraseology and the number of transmissions required to complete breakout instructions. In addition, they determined the number of descending breakout instructions and the number of blocked or clipped communications.

3.7.5.1 Use of Standard Breakout Phraseology and Standard Altitudes and Headings for Outer Approach Courses

Controllers were briefed on the standard phraseology to use in the event of a blunder and had an opportunity to rehearse the phraseology during practice runs. During actual test runs, most controllers used the standard phraseology in the initial breakout instructions. Table 6 details results of the use of standard phraseology for all blunders throughout the simulation.

Table 6. Use of Standard Breakout Phraseology in Initial Transmission

Phraseology	Usage
Standard: *"Traffic Alert, (call sign), turn left/right immediately heading (degrees), climb and maintain (altitude)*	93.3%
Non-standard: 1) Did not say "immediately"	2.7%
2) Reversed order of "Traffic Alert" and call sign *(e.g., "United Two-Seven-Four, Traffic Alert, turn right immediately...")*	2.0%
3) Reversed order of turn and climb instructions *(e.g., "...climb and maintain five thousand, turn left immediately heading zero niner zero.")*	1.3%
4) Split the breakout instruction into two transmissions *(e.g., "Traffic Alert, United Two-Seven-Four, turn right immediately heading zero niner zero." (Pilot readback). "United Two-Seven-Four, climb and maintain five thousand."*	0.7%

Most controllers used the standard altitudes and headings assigned to the outer localizer courses (the center approach course had no standard altitude or heading instruction). However, variations in phraseology did occur. Table 7 shows the frequencies and subsequent percentages of the use of standard phraseology in combination with the standard altitudes and headings over the course of the simulation.

Table 7. Use of Standard Breakout Phraseology in Combination with Standard Altitudes and Headings for Outer Localizer Courses

		Standard Altitudes and Headings for 4,000- and 5,300-Ft Configuration (in first transmission)	
		Used	Did Not Use
Standard Phraseology (in first transmission)	Used	71.4%	20.5%
	Did Not Use	6.3%	1.8%

During 71.4% of the blunder events, controllers used the standard phraseology and the standard altitudes and headings assigned to particular runways in the initial breakout transmission. During 20.5% of the blunders, controllers used the standard phraseology, but assigned

nonstandard headings and altitudes. During 6.3% of the blunders, controllers did not use the standard phraseology (e.g., forgot to say "Traffic Alert" or assigned only a heading), but did use the standard altitudes and headings assigned to particular runways. Lastly, during 1.8% of the blunders, controllers did not use the standard phraseology and did not use the standard altitudes and headings.

3.7.5.2 Multiple Transmissions

The test team also examined the number of transmissions made by the controller in directing an aircraft to break out of an approach. In 49.0% of the blunder events, controllers completed the breakout instructions in one transmission. In the remaining 51.0% of the blunder events, controllers transmitted two, three, four, and five times (i.e., multiple transmissions) to evading aircraft. The breakdown of the number of transmissions issued for all blunder events is shown in Figure 8.

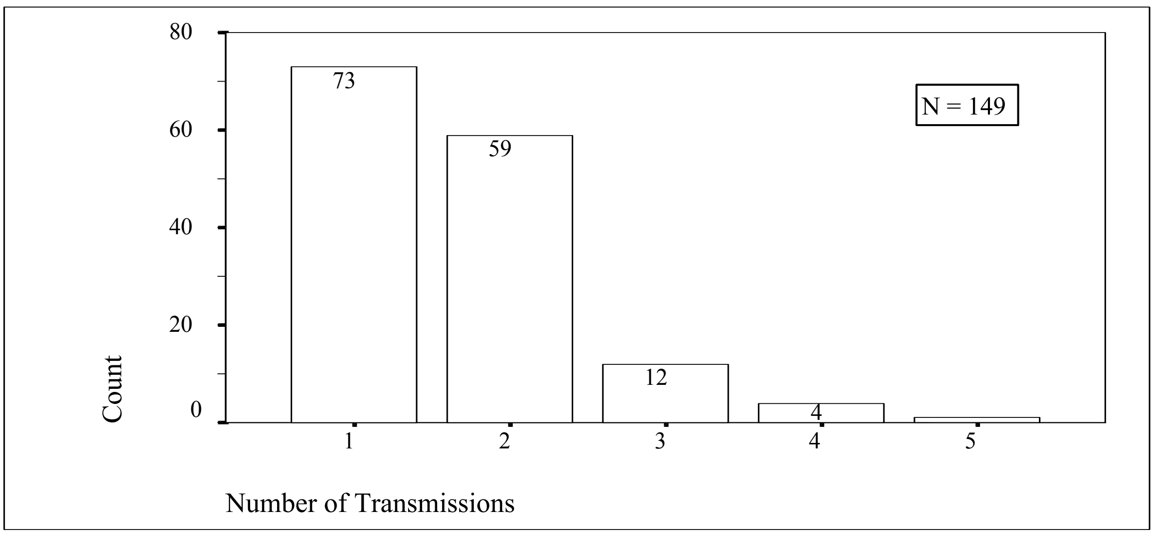


Figure 8. Number of transmissions required to complete breakout instructions for all blunders.

The test team categorized multiple transmissions by the contents of the subsequent transmissions. There were several reasons for the multiple controller transmissions. First, of the 51% of multiple transmissions, 35% were issued to offer additional information to the pilots. This information included phrases such as: "Best rate of climb/turn," "No delay in your turn/climb," "Expedite your turn/climb," "Tighten up your turn," "Traffic's deviating off your left/right off the other localizer," and "Traffic's less than a mile."

Controllers issued 22% of the multiple transmissions to repeat their initial breakout instructions. In most of these cases, controllers repeated breakout instructions because pilots of the evading aircraft did not verbally respond directly following the messages, and the controllers thought their messages were not received. In other cases, controllers repeated breakout instructions as a means of emphasizing the urgency of the situation.

Controllers issued 14% of the multiple transmissions to change their initial instructions. Sixteen of the 19 changes were to headings. Controllers first issued standard breakout headings of either 090 degrees or 270 degrees, then came back and changed them to greater turns, such as to 040 or 300 degrees. Two of the 19 changes were to altitudes. As with headings, controllers issued standard breakout altitudes first, then came back and changed them to greater altitudes. One of the 19 changes was both a heading and an altitude change from the prescribed standard breakout heading and altitude.

Controllers issued 22% of the multiple transmissions to combine types of information (additional, repeat, change, and split) within a transmission, as follows:

- 9%: change and additional information
- 7%: change and repeat
- 5%: repeat and additional information
- 1%: split

A split transmission means the controller only gave the turn in the initial instruction, and gave the altitude in one of the following transmissions. Only one time did a controller issue a split transmission. That blunder resulted in a TCV.

The rest of the multiple transmissions (7%) consisted of questions to evading aircraft pilots who offered no verbal response following breakout instructions such as, "Do you copy?" and "Immediately!" The transmissions also consisted of confirmatory statements, such as "Correct on the altitude" and "Affirmative."

3.7.5.3 Descending Breakout Instructions

Controllers issued four descending breakout instructions during the simulation. All controllers were briefed on the standard breakout phraseology, which included a climb instruction. However, they were still given the option to issue instructions as they deemed appropriate. All of the descent instructions were given when the evading aircraft were beyond 13 nm from the runway thresholds. The evading aircraft altitudes were all below the blundering aircraft altitudes at the start of the blunders.

3.7.5.4 Blocked and Clipped Breakout Instructions

Controllers issued a total of 282 breakout-related ATC transmissions over the course of the simulation. Of those transmissions, seven were blocked or clipped (i.e., five blocked, two clipped). Only two of the seven blocked/clipped transmissions occurred in controllers' initial breakout instructions. In the first case, the word "Traffic" was clipped from the breakout phraseology. The rest of the transmission was transmitted without interference; therefore, the clip was of no consequence. In the other case, the monitor controller issued breakout instructions as the evading aircraft was acknowledging the tower controller's clearance. The pilots did not hear any of the instruction. The controller repeated it quickly, however, and the endangered aircraft evaded while maintaining adequate separation.

Five of the blocked/clipped instructions occurred during second ATC transmissions (i.e., transmissions following the initial breakout instructions). In all cases, the controllers were repeating their initial instructions because they received no verbal readback from the pilots after the first issuance of instructions. The blocked/clipped transmissions did not affect breakout performance because in all cases the pilots were already executing breakout maneuvers.

3.7.6 Questionnaire Analyses

3.7.6.1 Controller Questionnaire Analyses

The MPAP test team gave each controller a Post-Simulation Questionnaire at the end of his participation in the simulation. Questions addressed the operational safety of the tested procedure, recommendations for improvements to the test design and procedures, communications workload, use of control strategies, adequacy of briefing information and training aids, and any additional comments. The researchers did not inform the controllers of the results of their participation or of the simulation as a whole prior to completing the questionnaires.

3.7.6.1.1 Operational Safety

In general, several participants thought that only a small margin for error would lead to a decrease in the safety of the operation. One individual said that, based on the simulation's blunder angle, a controller would have to apply breakout procedures to the evading aircraft without any delay. Two controllers made a distinction between the scenarios used in the simulation and "live" traffic worked in the field. They noted that the simulation scenarios were worst-case and remarked that those situations are exceptions in the field. Given this, they felt comfortable using the equipment to control runway traffic spaced, at a minimum, 4,000 ft apart.

Several controllers were concerned about vigilance and reaction times. Two participants said that the 4,000- and 5,300-ft spacings required high vigilance and "constant" monitoring by the final monitor. One participant remarked that "Awareness and attention must be maintained! Quick actions are needed! Controllers must watch all finals!"

Several participants were impressed with the display equipment. They saw the radar update speed and precision of the displays as safe features that "gave plenty of alert time to react."

3.7.6.1.2 Improvements to the Design and Procedures

One controller was concerned with operational procedures. He said that the procedure could be safely conducted only if separation standards were changed. If the old standards (i.e., 15 degrees, 1,000 ft) were used, he questioned using the center runway at all. He stressed that clearly defined procedures must be followed. One controller said if the same runway layout was used in the field as in the simulation, minimum separation could be run to the outer runways and departures from the center runway with the same capacity numbers. Another controller recommended that during a final with a stuck mike, the closest other final should be broken out until the radio is unstuck.

All of the participating controllers liked the PRM system. Several controllers offered suggestions for improving the human-computer interface of the system. Referring to predictor lines, one participant questioned the usefulness of predictor lines that erratically jumped around. To make them more useful and to reduce false alarms, he suggested either reducing their length and/or their sensitivity. Another participant said he would like to see lines graduated. For example, maybe a 12-15 second alert could be shown for 12-20 miles. Then, the standard 10-second alert could be given for about 6-12 miles followed by a 3-4 second alert for inside of 6 miles on final.

3.7.6.1.3 Assessment of Communications Workload

Most participants rated communications workload as moderate (8 out of 12). Four controllers noted that the prescribed phraseology used in the simulation was realistic and similar to that used in the field. One controller mentioned that the basic phraseology was short and simple. One said he liked beginning the breakout instruction with "Traffic Alert" followed by the aircraft call sign.

Several participants were concerned about having enough time to react. One controller said the only difficult part was getting the breakout transmission right the first time because there did not seem to be enough time for a second transmission. Another controller also had this concern, noting that the time available to detect a blunder, then to issue go-around instructions, and then to coordinate with other controllers, was short.

One participant was concerned about a communications frequency getting a "stuck mike" during a final. Another was concerned that miscommunications (too many readbacks and hearbacks) could result in a conflict.

3.7.6.1.4 Use of a Specific Control Strategy

When asked about using a particular strategy to control the traffic, every participant discussed a visual scanning technique. Comments included general statements like the following: "Constant scanning was necessary," "you must have a quick scan," "watch all finals...," and "rapid continuous scanning of aircraft on my final and adjacent runway (was needed)." Others wrote descriptions of more specific strategies they used. One controller reported using a linear search strategy by moving from the left side of the display toward the right and from top to bottom. Another participant reported using a global search strategy by grouping targets. He remarked, "I tried to sit back and get an overview of the display to watch for blunders, rather than to concentrate on individual aircraft." One participant reported using a combination linear and global search strategy. "I did not scan plane-to-plane but rather three-abreast, as a group, on final (global strategy). Up and back down (linear strategy)."

Participants also discussed their communications strategies. Almost every respondent mentioned the value of communicating with other controllers. Comments addressing the use of inter-controller communication included the following: "After a breakout, I would let the other controller know what altitude and heading I was using." "(I would) advise the other controller if the aircraft was NORDO or not." "Intense listening to the other controllers (was essential)." "When applying breakout procedures to one of my aircraft, I listened for the adjacent controller applying the breakout procedure."

Three participants highlighted the value of the new phraseology. One said, "(I) listened for and keyed on ‘Traffic Alert’." Another said, "I would usually try and say, ‘Traffic Alert’ loud enough to alert the other monitors, and I would listen to them to say, ‘Traffic Alert’ in case they caught a blunder before I would." A third summed it up by saying, "’Traffic Alert’ not only alerts the aircraft but the controllers as well."

3.7.6.1.5 Adequacy of Briefing Information and Training Aids

In general, the participants gave high ratings to the briefing information and training aids. Ratings ranged from "good" or "acceptable" to "very adequate" and "excellent." Controllers felt that the briefing information and training aids prepared them for the simulation. Some participants discussed the realism of the simulation. One participant remarked that it was good to see the difference between a blunder on a 1:1 ratio and on a 4:1 ratio.

One controller asked about the role the Traffic Collision Alert System (TCAS) would play in real life scenarios. For example, "Will a pilot take the controller clearance if TCAS is barking something else?" This participant suggested that a short explanation about TCAS’s role in the briefing might help. Another controller suggested that it would be beneficial to give a briefing or hands-on practice in adjusting features on the equipment.

3.7.6.2 Pilot Questionnaire Analyses

The subject pilots brought real world aviation expertise to the simulation. At the end of their participation in the simulation, 36 out of 37 flight simulator pilots completed Flight Crew Opinion Surveys. These surveys tapped the wealth of pilot experience that was available. The intended users had a chance to evaluate the training materials, the information page, the additions to the approach plates, and the new phraseology. All pilots were encouraged to add written comments.

3.7.6.2.1 Preferred Method of Flying Approaches

The pilots were asked how they would fly a simultaneous close parallel approach. This information will be used as an aid in assigning a realistic ratio of autopilot, flight director, and raw data flown approaches in future simulations. The B727 and glass cockpit pilots had similar opinions with 83% preferring a coupled autopilot approach. GAT pilots were evenly split between hand flying the approach using only the flight director and flying the approach using a coupled autopilot. No pilot would choose to fly the approach using raw data only. Figure 9 shows the amount of votes each method received from all 36 pilots who completed the survey.

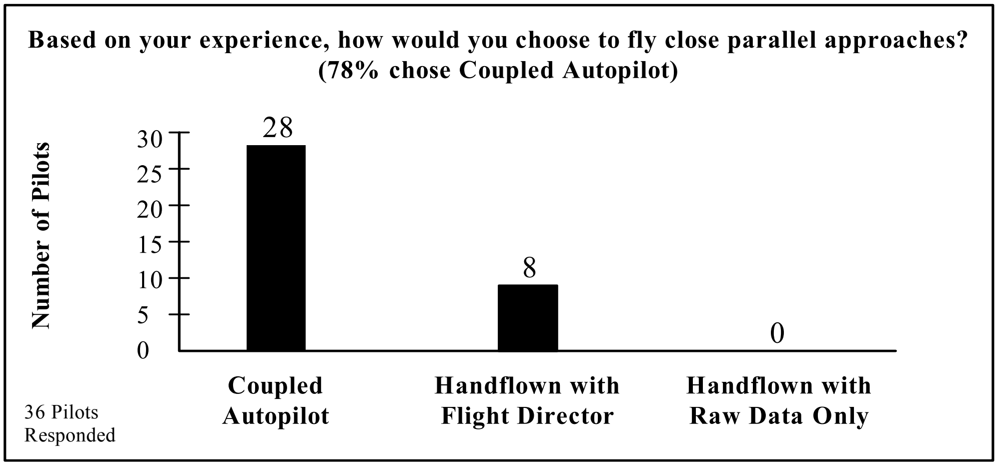


Figure 9. Preferred method of flying close parallel approaches.

3.7.6.2.2 Amount of Crew Coordination Required

It was important to ascertain if more crew coordination was required for ILS PRM approaches than for normal ILS approaches. Feedback from the pilots on this issue could be used in the establishment of future training requirements. As shown in Figure 10, 70% of the pilots agreed that more crew coordination was required for simultaneous approaches than for normal approaches. GAT pilots were not included in this survey question because only single pilot operations were conducted in that simulator.

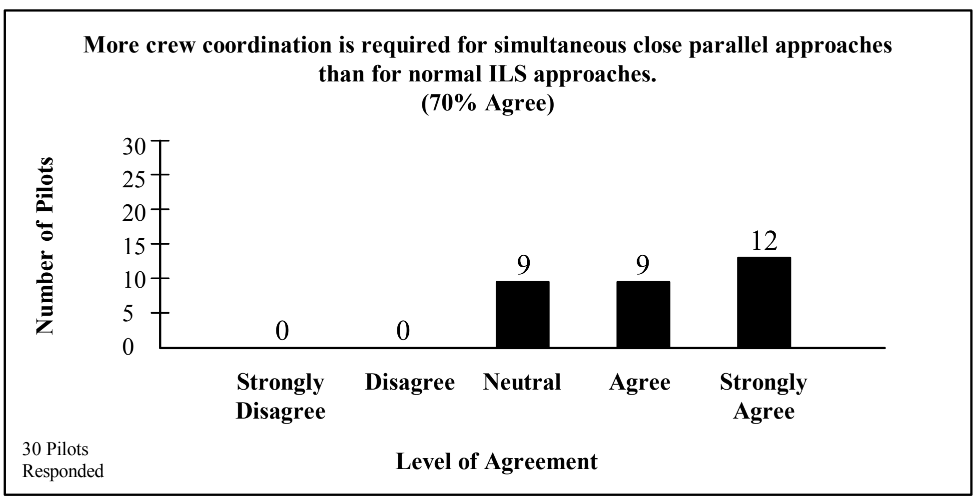
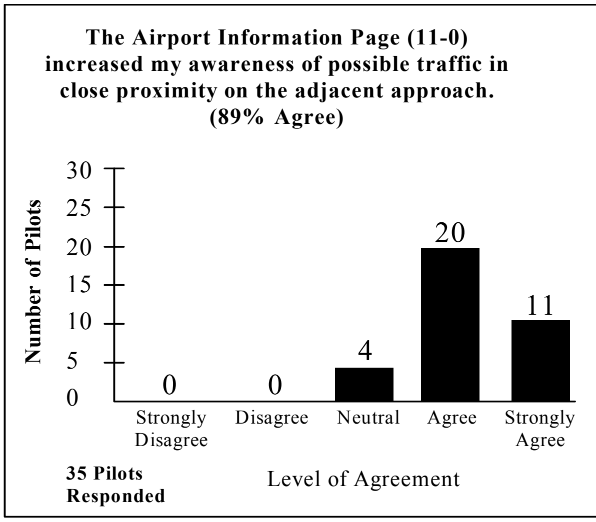


Figure 10. Crew coordination for close parallel approaches as compared to normal approaches.

3.7.6.2.3 Increased Awareness Through the Airport Information Page

The MPAP test team made several changes to the airport information page for the closely spaced approaches. They subsequently asked the pilots how these changes affected their awareness of adjacent aircraft and of close parallel approach procedures. The majority of pilots thought that their awareness increased in both areas, as shown in Figures 11 and 12.



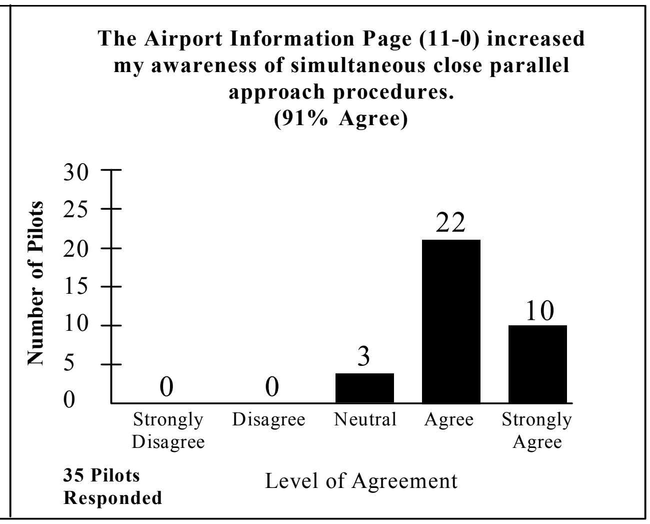


Figure 11. Airport information page: Awareness of adjacent aircraft.

Figure 12. Airport information page: Awareness of procedures.

3.7.6.2.4 New Air Traffic Control Phraseology

The simulation used new controller phraseology in the breakout instructions. It was important to learn how the pilots felt about this new phraseology. The data in Figure 13 show that 83% of the pilots surveyed thought the new phraseology was more effective than what was used in previous simulations.

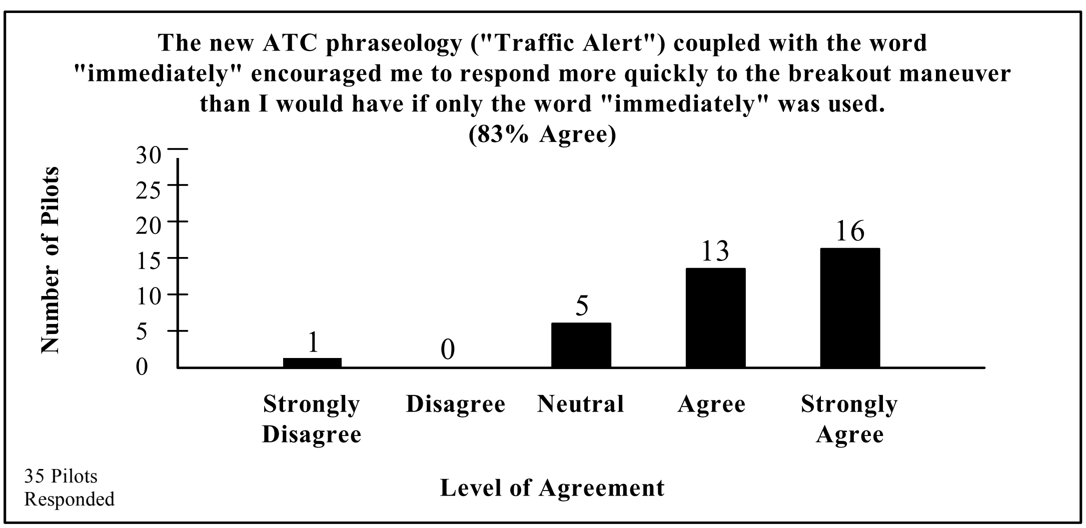


Figure 13. New ATC phraseology in relation to the production of faster pilot response times.

3.7.6.2.5 Increased Awareness Through Video

The video, “RDU Precision Runway Monitor: A Pilots' Approach,” was considered to be an important part of the pilot training. As illustrated in Figure 14, 78% of the pilots agreed to the statement, "The video increased my awareness of simultaneous close parallel approach operations."

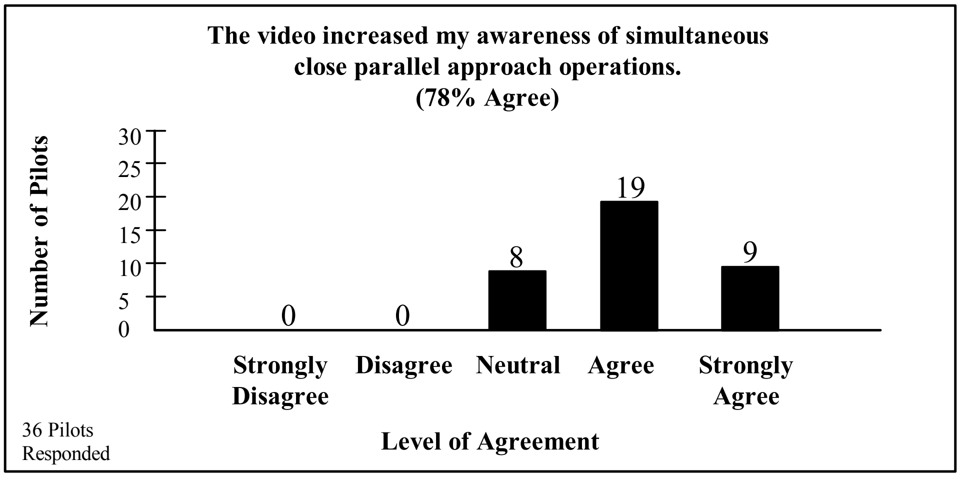
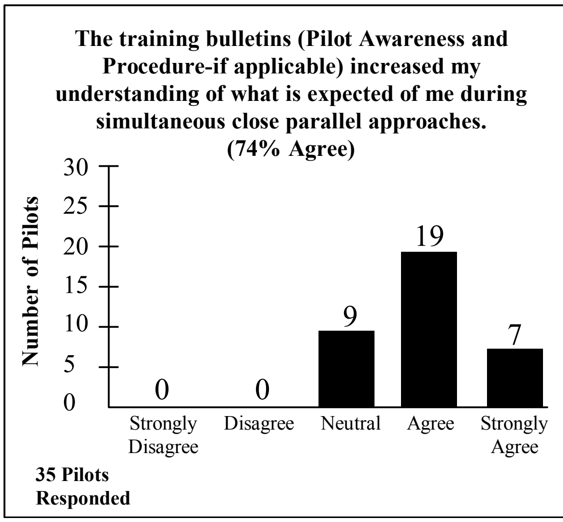


Figure 14. Video in relation to increased operational awareness.

3.7.6.2.6 Effect of Pilot Bulletins on Performance

Two questions addressed the effectiveness of the training bulletins. The first question asked the pilots whether the bulletins provided a better understanding of what was expected of them during simultaneous close parallel approaches. The data in Figure 15 show that 74% of the pilots agreed that the bulletins increased their understanding of the procedure. The second question asked the pilots if the training bulletins helped them to execute ATC-directed breakout maneuvers. The data in Figure 16 show that 72% of the pilots agreed that the training bulletins aided in the execution of breakouts.



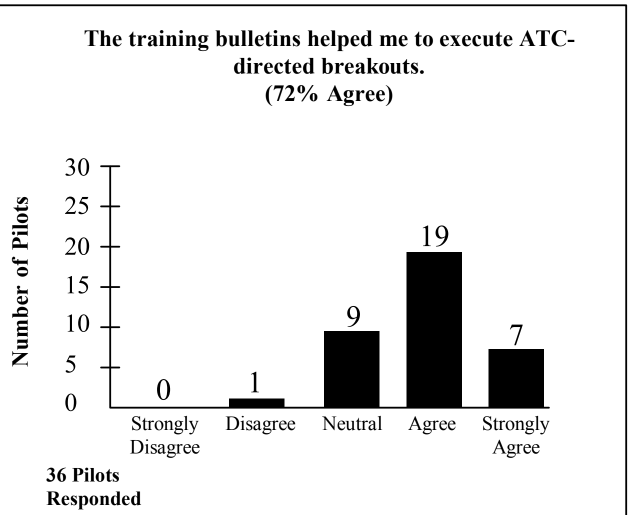


Figure 15. Pilot training bulletin: Understanding. Figure 16. Pilot training bulletin: Execution.

3.7.6.2.7 Rank of Importance

The next survey question asked the pilots to rate the importance of items used during the simulation. The most important item according to the pilots was the use of the phraseology, "Traffic Alert." More than half of the pilots rated this item as a 10. The responses to this question are depicted in Figure 17.

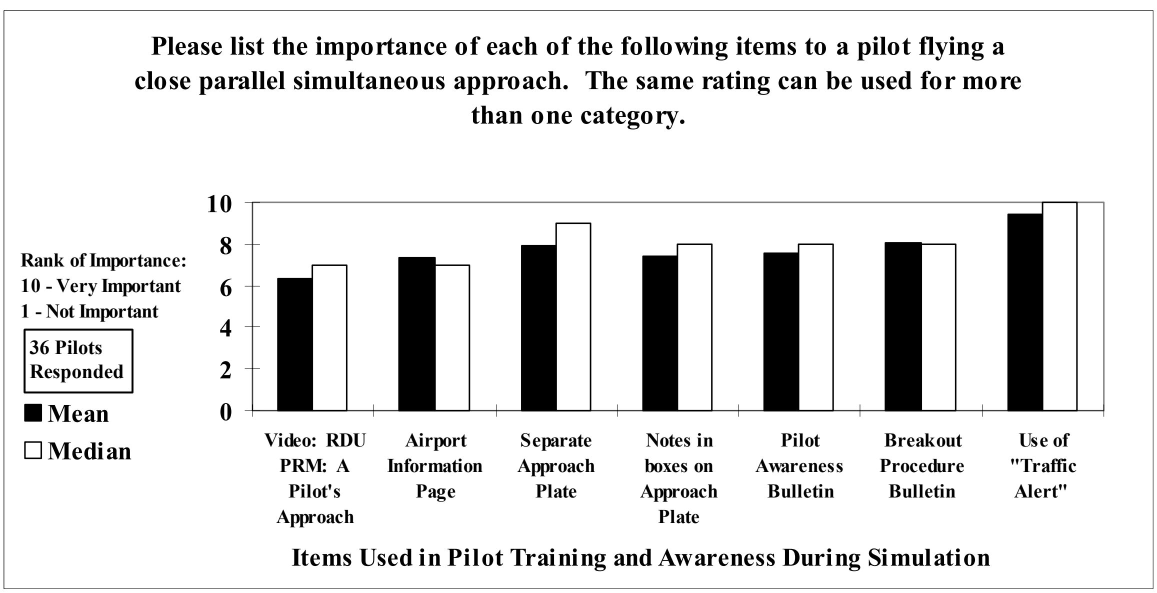


Figure 17. Rank of importance of items to flying a close parallel approach.

3.7.6.2.8 Traffic Collision Alert System Mode for Simultaneous Close Parallel Approaches

The final two survey questions addressed the use of TCAS II. Only pilots with TCAS experience answered this question. In order to assess the probability of a pilot disregarding controller breakout instructions and following a resolution advisory (RA) from TCAS, site coordinators asked pilots to place themselves in the scenario of receiving an RA and conflicting controller breakout instructions while on the close parallel approach. They then asked the pilots what TCAS mode they would choose if given the likelihood of a TCAS/final monitor controller conflict. The data in Figure 18 contain the pilot responses to the conflict scenario. The data in Figure 19 show that a majority of the pilots would choose to place their TCAS in the TA mode prior to the approach if they considered the probability of conflicting instructions. The significant aspects of these survey questions is that 47% of the pilots with TCAS experience chose to follow the RA command and, if given a choice, the majority of pilots would choose to avoid a conflict by placing TCAS in the TA-only mode.

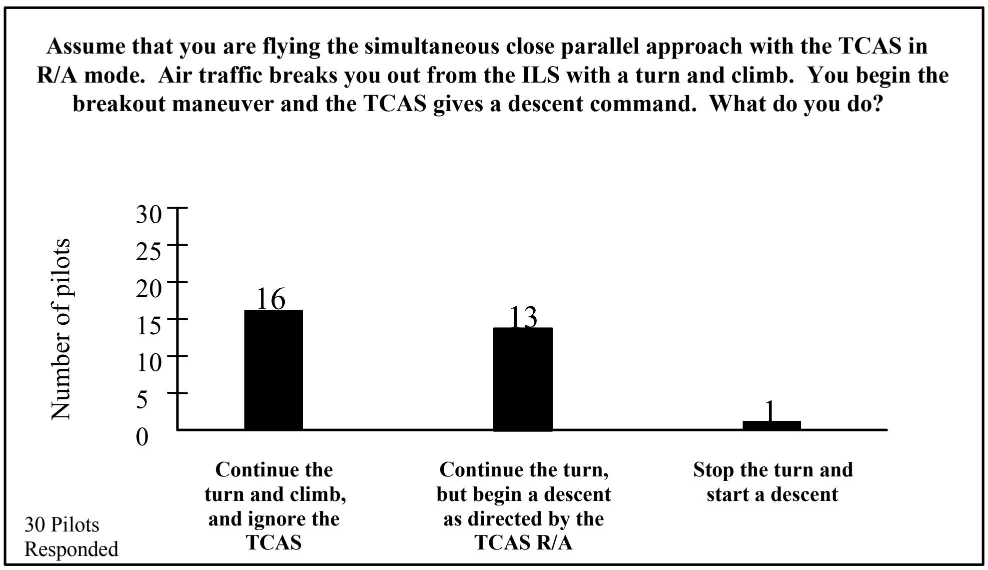


Figure 18. TCAS and final monitor controller conflict scenario.

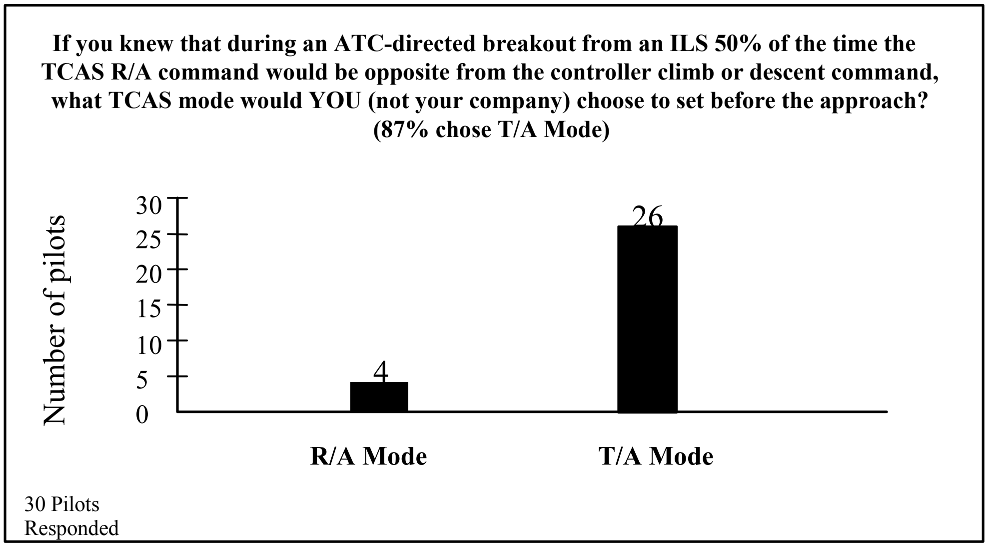


Figure 19. Pilot choice of TCAS mode considering predicted conflict with final monitor controller.

4. Summary

In the August 1995 4,000- and 5,300-ft triple simultaneous approach simulation, an unacceptable TCV rate resulted and the MPAP TWG did not recommend the procedure for approval. They identified insufficient controller training as a contributing factor to the unacceptable test results. Controllers were not familiar with the PRM equipment and did not receive adequate hands-on training time with the FMA display format and functions prior to the testing. In addition, the breakout phraseology was lengthy. Controllers had difficulty recalling the exact wording when the time came to use it, and, as a result, breakout phraseologies varied in content and duration, sometimes resulting in confusion in the cockpit.

Following the August 1995 triple simulation, the MPAP TWG made significant modifications to the controller training components. First, they increased the amount of hands-on training with the PRM equipment to 8 hours per controller. Controllers who participated in the August 1995 triple simulation received only 2 hours of hands-on training each prior to the test. The 8 hours of training in the April 1996 triple simulation gave controllers sufficient time to become accustomed to the equipment and to practice detecting and resolving blunders. The 8 hours of practice time is recommended for all controllers who monitor this simultaneous approach operation in the field upon approval of the procedure.

In addition to the extended training time, the MPAP TWG shortened the controller breakout phraseology from the previous 4,000- and 5,300-ft simulation. Controllers rehearsed the phraseology in the practice sessions and had no problems employing it during the actual test runs. The new phraseology proved to be very effective in both heightening the awareness of listeners on the frequency as to the urgency of the situation and in preventing detrimental effects of blocked and clipped transmissions. The phrase “Traffic Alert” at the beginning of the message conveyed urgency; however, if for some reason the phrase was blocked, pilots on the frequency could still hear the aircraft call sign of the endangered aircraft and could therefore respond without delay.

Other improvements to the controller-training program were also effective in enabling a successful simultaneous triple approach operation. Such improvements included the emphasis placed on completing the breakout instruction in one transmission and the increased standard breakout altitudes for the outer localizer courses.

The pilot training program introduced in the August 1995 triple simulation was also clearly contributive to the success of the second triple simultaneous approach simulation. Pilots were given awareness training that emphasized the importance of reacting promptly to controller breakout instructions during close parallel approaches. In addition, pilots were instructed to hand-fly all breakouts, which although not quantified in this simulation, has been shown in recent simulations to significantly reduce the time-to-turn during breakouts in certain aircraft types.

The April 1996 4,000- and 5,300-ft simulation met all of the TWG's test criteria. The real-time TCV rate was 2.4%, with an upper-confidence limit for the true value of 8.51%. Although the upper-confidence limit for the TCV rate from the real-time simulation was larger than the test criterion of 5.1%, the ASAT Monte Carlo simulation had an observed TCV rate of 0.899% with an upper-confidence limit of 0.979%. These results were considerably less than the maximum acceptable TCV rate of 5.1%. The MPAP test team determined that the rates for the proximate pairs of runways met the criterion for dual approaches. In addition, no flight simulator made an unintended entry into the NTZ, and only five NBOs (0.2%) resulted with normal flight behavior. The TWG considered both results to be acceptable frequencies. They also determined the controller communications workload to be acceptable.

5. Conclusions

This simulation tested the procedure for simultaneous ILS approaches to three parallel runways spaced 4,000 and 5,300 ft apart using the PRM system with a 1.0-second update rate. The MPAP TWG evaluated both controller and pilot effectiveness at resolving conflicts, the frequency of NTZ entries and NBOs, and the ability of the system to support a target level of risk of no more than one fatal accident per 25,000,000 approaches. Based upon their observations and evaluations, the TWG recommends this procedure, as tested, for approval in the operational environment.

Glossary

At-Risk Blunder - (As defined for this simulation) A blunder in which two aircraft would have come within 500 ft of one another without controller intervention.

Blunder - (As defined for this simulation) An unexpected turn by an aircraft already established on the localizer toward another aircraft on an adjacent approach.

Breakout - A technique used to direct aircraft out of the approach stream. In the context of close parallel operations, a breakout is used to direct an aircraft away from a deviating aircraft while simultaneous operations are being conducted.

Closest Point of Approach - (As defined for this simulation) The smallest slant range distance between two aircraft involved in a conflict. The distance is measured from the center of each aircraft.

Confidence Interval - A statistically defined range of values of the population mean, any one of which is likely to be represented by the sample means.

Conflict - (As defined for this simulation) An event in which two or more aircraft approach each other with less than the minimum allowable airspace separation. A conflict occurs if there is less than 1,000 ft vertical or 3 nm horizontal distance between aircraft, unless the aircraft are established on ILS approaches and separated by an NTZ during simultaneous ILS approaches.

Controller Technical Observer - An individual who observes a monitor controller position during each simulation run. Duties include the following: documenting discrepancies between issued control instructions and actual aircraft responses; assisting in alerting responsible parties to correct any problems that may occur during the test (e.g., computer failure, stuck microphone); assisting controllers in preparation of reports; and documenting their evaluation of the data in a technical observer assessment at the end of the simulation.

Closest Point of Approach prediction tool - A software tool used by the simulation test director that presents a window of aircraft alignments for predicting separation between aircraft.

Final Monitor Aid - A high-resolution color display that is equipped with the controller alert system hardware and software used in the PRM system. The display includes alert algorithms providing the target predictors, a color change alert when a target penetrates or is predicted to penetrate the NTZ, a color change alert if the aircraft transponder becomes inoperative, synthesized voice alerts, digital mapping, and like features contained in the PRM system (FAA, 1996a; FAR, 1996).

Final Monitor Controller – ATC Specialist assigned to radar monitor the flight paths of aircraft during simultaneous parallel and simultaneous close parallel ILS approach operations. Each runway is assigned a final monitor controller during simultaneous parallel and simultaneous close parallel ILS approaches. Final monitor controllers shall utilize the PRM system during simultaneous close parallel ILS approaches. (FAA, 1996a).

Flight Technical Error - (As defined for this simulation) The accuracy with which the pilot controls the aircraft as measured by the actual aircraft position with respect to the desired aircraft position. It does not include blunders.

Glide Slope Intercept Altitude - The minimum altitude to intercept the glide slope/path on a precision approach. The intersection of the published intercept altitude with the glide slope/path, designated on Government charts by the lightning bolt symbol, is the precision FAF; however, when ATC directs a lower altitude, the resultant lower altitude intercept position is then the FAF. (FAA, 1996a; FAR, 1996)

Indicated Airspeed - The speed shown on the aircraft airspeed indicator. This is the speed used in pilot/controller communications under the general terms, airspeed. (FAA, 1996a; FAR, 1996)

Instrument Landing System - A precision instrument approach system, which normally consists of the following electronic components and visual aids: localizer, glide slope, outer marker, middle marker, and approach lights. (FAA, 1996a; FAR, 1996)

Instrument Meteorological Conditions - Meteorological conditions expressed in terms of visibility, distance from cloud, and ceiling less than the minima specified for visual meteorological conditions. (FAA, 1996a; FAR, 1996)

Mean - The arithmetic average; or the sum of measurements divided by the total number of measurements.

Median - The middle value when measurements are arranged in order of magnitude; the value at the 50th percentile of a set of measurements.

Multiple Parallel Approach Program Technical Work Group - A group of FAA employees representing several different offices (e.g., Secondary Surveillance Product Office, Office of System Capacity) that assembles to make recommendations on multiple parallel approach procedures.

National Airspace System - The common network of U.S. airspace; air navigation facilities, equipment and services, airports or landing areas; aeronautical charts, information and services; rules, regulations and procedures, technical information, and manpower and material. Included are system components shared jointly with the military. (FAA, 1996a; FAR, 1996)

No Transgression Zone - A 2,000 ft wide zone, located an equal distance between parallel runway final approach courses, in which flight is not allowed. (FAA, 1996a)

Normal Operation Zone - The operating zone within which aircraft flight remains during normal independent simultaneous parallel ILS approaches. (FAA, 1996a)

Nuisance Breakout - (As defined for this simulation) An event in which an aircraft is broken out of its final approach for reasons other than a blunder, loss of longitudinal separation, or lost beacon signal (i.e., aircraft goes into coast).

Outer Marker - A marker beacon at or near the glide slope intercept altitude of an ILS approach. It is keyed to transmit two dashes per second on a 400 Hz tone, which is received aurally and visually by compatible airborne equipment. The Outer Marker is normally located four to seven miles from the runway threshold on the extended centerline of the runway. (FAA, 1996a; FAR, 1996)

Precision Runway Monitor System - A system that provides air traffic controllers with high-precision secondary surveillance data for aircraft on final approach to closely spaced parallel runways. High-resolution color monitoring displays (FMAs) are required to present surveillance track data to controllers along with detailed maps depicting approaches and the NTZ. (FAA, 1996a; FAR, 1996)

Simulation Pilot Operator - A person who operates a TGF computer workstation and controls the trajectory of TGF aircraft by computer input messages. The SPO usually communicates via voice circuits to ATC personnel in the laboratory that is being used to simulate an operational facility.

Simultaneous ILS Approaches - An approach system permitting simultaneous ILS/Microwave Landing System approaches to airports having parallel runways separated by at least 4,300 ft between centerlines. Integral parts of the total system are ILS/MLS, radar, communications, ATC procedures, and appropriate airborne equipment. (FAA, 1996a; FAR, 1996)

Site Coordinator - A current or retired airline pilot with MPAP real-time simulation and flight simulator experience who observes aircrews during their approaches. Duties include briefing aircrews, providing pilots with flight information, documenting approach information, and administering questionnaires to the pilots.

Target Generation Facility - An advanced simulation system designed to support testing of current and future ATC systems at the William J. Hughes Technical Center. The TGF is capable of modeling a logical view of the ATC environment (airspace volume including geographic data, weather data, navigation aids, radar sensors, airport data, and air routes) as well as simulating dynamic data associated with the movement and control of aircraft through the selected airspace.

Target Generation Facility Aircraft - Targets generated by the TGF at the William J. Hughes Technical Center. TGF aircraft are used to provide additional traffic and to initiate blunders.

Test Criterion Violation - (As defined for this simulation) An event that occurs when the CPA between two aircraft, after the initiation of a blunder, is less than 500 ft.

Test Director - The individual responsible for cueing blunder initiation through the use of the CPA prediction tool and by assessing the blunder scripts. The test director is the liaison between the William J. Hughes Technical Center and the flight simulator sites during the simulation.

Total Navigation System Error - (As defined for this simulation) The difference between the actual flight path of the aircraft and the path it is intending to fly. FTE, avionics error, ILS signal error, and weather cause it.

Worst-Case Blunder - (As defined for this simulation) A blunder in which the blundering aircraft turns 30 degrees towards an adjacent approach course and does not respond to controller instructions to return to course.

Acronyms

ASAT	Airspace Simulation and Analysis for TERPS
ATC	Air Traffic Control
ATIS	Automatic Terminal Information System
CPA	Closest Point of Approach
E-Scan	Electronic Scanning
EI	External Interface
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FMA	Final Monitor Aid
FTE	Flight Technical Error
GAT	General Aviation Trainer
IAS	Indicated Airspeed
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
MPAP	Multiple Parallel Approach Program
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NBO	Nuisance Breakout
NOZ	Normal Operating Zone
NTZ	No Transgression Zone
PRM	Precision Runway Monitor
RA	Resolution Advisory
rms	Root Mean Square
SD	Standard Deviation
SPO	Simulation Pilot Operator
SPW	Simulation Pilot Workstation
TA	Traffic Alert
TCAS	Traffic Collision Alert System
TCV	Test Criterion Violation
TGF	Target Generation Facility
TNSE	Total Navigation System Error
TRACON	Terminal Radar Approach Control
TWG	Technical Work Group
WCB	Worst-Case Blunder

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